

Chapter 1

Science and Technology in Times of Transition: the 1940s and 1990s

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Introduction

Chapter Background

The National Science Board's (NSB) *Science and Engineering Indicators – 1998* report contained several cross-cutting themes; namely,

- ◆ increasing globalization of science, technology, and the economy;
- ◆ greater emphasis on science and engineering education and training;
- ◆ structural and priority changes in the science and engineering enterprise; and
- ◆ increasing impacts of science and technology on our daily lives.

Many of the trends discussed in detail in the remaining chapters of *Science and Engineering Indicators – 2000* suggest the persistence of these themes, supporting the Board's conclusion about their importance in characterizing the policy context of the U.S. science and engineering enterprise in this time of transition to the 21st century.

Publication of *Science and Engineering Indicators – 2000* coincides with the 50th anniversary of the creation of the National Science Foundation (NSF) in 1950. As the NSB and NSF prepare to make a transition into their second half-century, the Board believes it would be useful to reflect on the conditions that characterized U.S. science and engineering 50 years ago. NSF was created near the end of another significant time of transition from a period in which the country's science and engineering resources were mobilized for World War II to a period in which a system designed to facilitate partnerships in support of a broader set of national objectives had been put in place. Although the specific issues and concerns evident in documents from the late 1940s differ from those that are familiar today, several current science policy themes have antecedents dating from the period. A better understanding of the origins of these enduring themes can help in planning for the future.

Each of the remaining chapters of *Science and Engineering Indicators – 2000* touches upon notable themes and issues from the 1940s that are germane to the specific topics it considers. However, their emphasis is on the current situation, as has been the case for all earlier editions in the *Science and Engineering Indicators* series. The purpose of this chapter is to set the stage for the brief historical notes presented in these chapters by comparing and contrasting the resources available within the U.S. science and engineering enterprise, its organization, and significant science policy issues in the 1940s and in the 1990s. In effect, it presents two "snapshots," taken 50 years apart, and in that respect differs from the later chapters in this report, as well as chapters that have appeared in earlier reports in this series.

Chapter Organization

The next section of this chapter, "Highlights of the First Time of Transition: 1945–51," provides an overview of some of the principal congressional and administration decisions and actions that shaped U.S. science policy between the end of World War II and the establishment of the first Presidential Science Advisory Committee (PSAC) in April 1951.

"Early Visions/Key Policy Documents" considers the contexts of, and the visions contained in, two key policy documents from that first time of transition: *Science—The Endless Frontier* (Bush 1945a), delivered to President Harry S. Truman in July 1945, and *Science and Public Policy* (Steelman 1947), delivered to Truman in August 1947.

Almost from the outset, the Board and Foundation have assigned a high priority to gathering and disseminating quantitative and qualitative information relevant to science policy. "Monitoring the Condition of the Science and Engineering Enterprise" discusses the expansion of activities in this area, culminating with the Board's decision to issue its first *Science Indicators* report in 1973 (NSB 1973).

All recent U.S. presidents, beginning with Franklin D. Roosevelt, have recognized the importance of science and engineering to the Nation. President Truman was the first to do so in a public address that he gave in September 1948 at the 100th anniversary meeting of the American Association for the Advancement of Science (AAAS) (Truman 1948). A section entitled "Presidential Statements" compares and contrasts the themes in that speech with those in the address of President William J. Clinton at the 150th anniversary meeting of the AAAS in February 1998 as a means of examining continuities and changes in U.S. science policy during the past half-century (Clinton 1998).

"Current Visions/Key Policy Documents" offers a snapshot of the current period of transition by highlighting two key policy documents from the 1990s: *Science in the National Interest* (Clinton and Gore 1994) and *Unlocking Our Future* (U.S. House of Representatives Science Committee 1998). A section entitled "Advances in Science and Engineering" follows, with illustrative examples of advances that have occurred in large measure from the policies set in place in the 1940s and maintained in broad outline during the ensuing half-century.

Similarities and distinctions between the earlier time of transition and the current situation are examined in more detail in "Enduring Themes: Continuity and Change," where the emphases associated with significant themes identified by the key documents from the 1940s are compared and contrasted with those in the key documents of the 1990s. Specific trends and issues are highlighted in the succeeding chapters of *Science and Engineering Indicators – 2000*.

"Current Emerging Themes," the final section of the chapter, identifies themes that the Board believes will be important in the first decade of the new century, several of which it intends to address in detail in a series of forthcoming occasional papers.

Highlights of the First Time of Transition: 1945–51

The National Science Foundation Act of 1950,¹ which President Truman signed into law on May 10 of that year, gave NSF the mandate “to promote the progress of science; to advance the national health, prosperity, and welfare; and for other purposes.” The breadth of this mandate indicates that a bipartisan majority existed in Congress about the significance of science and engineering in addressing matters of national importance. NSF’s creation occurred near the end of the time of transition in which the basis of U.S. science policy was established and many of the principal issues and concerns comprised by that policy were articulated. But the concept of a National Science Foundation had emerged several years earlier. (See text table 1-1.)

Emergence of a Concept

More than a year before World War II ended on September 2, 1945, a few members of Congress and a handful of officials in the Roosevelt Administration had foreseen the essential roles that science and engineering would play dur-

ing peacetime. Early in 1944, Senator Harley M. Kilgore (D-WV), a member of a Select Committee chaired by Senator Harry S Truman (D-MO) investigating the war production effort, introduced a bill to create a National Science Foundation (Kevles 1977). While Kilgore’s National Science Foundation would have given priority to Federal Government laboratories in the disposition of funds, it would also have been authorized to award research contracts and scholarships to colleges and universities. Kilgore’s colleagues in the Senate convinced him that hearings on his proposed bill should be postponed until after the end of the war.

In November 1944, President Franklin D. Roosevelt addressed a letter to Vannevar Bush, his *de facto* science advisor, asking for his advice on how the lessons learned from the World War II organization of science and engineering could be applied in peacetime. Bush’s response came seven months later in July 1945, when he delivered the requested report, *Science—The Endless Frontier*, to President Truman (Bush 1945a). By the end of that month, Senator Warren Magnuson (D-WA) had introduced legislation to implement the centerpiece recommendation of what is commonly referred to as the Bush report: namely, to establish a National Research Foundation to provide Federal funds for research to nonprofit institutions outside of the Federal Government (including

Text table 1-1.

Highlights of the first transition

Year	Month	Science policy events	Other events
1944	February November	Kilgore legislation introduced in Senate Roosevelt’s letter to Bush	Roosevelt reelected
1945	April May July September October	<i>Science—The Endless Frontier</i> Senate hearings on NSF began	Death of Roosevelt End of World War II in Europe End of World War II in the Pacific
1946	August October	AEC and ONR created Steelman board established	
1947	June August	<i>Science and Public Policy</i>	Marshall Plan announced
1948	February September November	Truman speech at AAAS meeting	First electronic computer Truman reelected
1950	May June December	NSF created Truman addressed first NSB meeting	Korean War began United Nations forces abandon Pyongyang and Seoul
1951	April July	First NSF director sworn in; SAC/ODM established NSF Annual Report, with R&D expenditure data included	Gen. MacArthur relieved of command of United Nations troops in Korea

civilian defense research and medical research) and to award scholarships and fellowships to aspiring scientists and engineers. Within a few days, Senator Kilgore reintroduced a revised version of his earlier bill.

The Kilgore and Magnuson bills differed both in the types of institution given priority for research support and in their proposed administrative structure. Deep-seated disagreements on the latter issue persisted and delayed the creation of NSF for almost five years. Between 1945 and 1950, a vigorous public debate took place on the institutional framework for science. That debate, which included the nature of a National Science Foundation, took five years to resolve; during this period, both the Office of Naval Research (ONR) and the National Institutes of Health (NIH) were created, reducing the scope of the proposed foundation.²

Congressional Initiatives

Joint hearings on the Magnuson and Kilgore bills, which began in October 1945, were among the first in a series of congressional debates and administration actions whose outcomes determined the character of Federal Government support for, and involvement with, science and technology that has largely persisted for the past half-century. Congress, for the first time, began to deal with significant science- and technology-related issues on a more or less continual basis. Its extensive, open-to-the-public committee hearings called heavily on members of the public and the scientific community as it sought to forge new policies and create a new organizational framework for Federal Government science.

The most controversial issue addressed by Congress during the immediate postwar years had to do with whether the control of nuclear energy should remain with the military or be consigned to civilian hands (Smith 1965). On August 1, 1946, following extensive and frequently impassioned hearings that involved many of the younger scientists who had been engaged in the ultra-secret World War II work to produce nuclear weapons, Congress established the Atomic Energy Commission (AEC), to be governed by a five-member commission of presidentially appointed civilians.³

On August 1, 1946, Congress also created the ONR.⁴ Both AEC and ONR soon began to support university research in fields broadly related to their respective missions. Two years later, NIH within the Public Health Service began to follow suit by supporting research through contracts to the Nation's medical schools. Prior to that time, the agency's research program had focused on specific health-related problems and was carried out largely intramurally. Thus by the time NSF was created in May 1950, several Federal mission agencies had already gained considerable experience in funding university research.

²See England (1983, 25–110).

³An Act for the Development and Control of Atomic Energy, Public Law 585, 79th Congress, 2nd Session.

⁴An Act to Establish an Office of Naval Research in the Department of the Navy, Public Law 588, 79th Congress, 2nd Session. The Secretary of the Navy had used his emergency authority to create ONR on a temporary, interim basis in May 1945.

Administration Actions

On October 17, 1946, in response to the rapid expansion in the Federal Government's organization for science, President Truman established the President's Scientific Research Board (PSRB) chaired by John R. Steelman, who became The Assistant to the President on January 1, 1947. The first of five volumes of PSRB's report, entitled *Science and Public Policy* and commonly referred to as the Steelman report (Steelman 1947), was released on August 27, 1947. This report analyzed, and made recommendations about, the entire Federal science and technology system; the relations between research in the Federal Government, industrial, and academic sectors; and the condition of science teaching at all levels, from the primary grades through graduate school. It based its analysis of the state of the Nation's science and technology enterprise on extensive sets of data and several specially commissioned studies.

The President drew on the Steelman report to propose a national science policy in his September 1948 address to AAAS (Truman 1948). One element of his proposed policy—to create a National Science Foundation—was fulfilled when Congress passed the National Science Foundation Act of 1950.⁵

The Act that Truman signed into law in May 1950 defined NSF as “an independent agency ... [to] consist of a National Science Board and a Director.”⁶ Accordingly, the Foundation was officially activated when the Board convened for the first time on December 12, 1950, in the White House (England 1983, 123). President Truman joined the first NSB meeting and addressed the Board. Thereafter, the chairman reported to the President on actions taken by the Board during the morning session. Those actions consisted of the election of the chairman (James B. Conant) and vice chairman (Edwin B. Fred), establishment of a committee to recommend to the President names of people who might be appointed to the position of director of NSF, and establishment of an executive committee.

Impacts of the Korean War

President Truman had a great deal on his mind at the time he addressed the NSB's first meeting. A month earlier, the People's Republic of China had intervened in the Korean War.⁷

⁵Several long-forgotten controversies delayed the Congress's passage of this Act, perhaps because the value of basic research was not sufficiently understood a half-century ago. These controversies were resolved through the patient work of several key individuals. William D. Carey in the Bureau of the Budget (BoB) continued to insist to his colleagues that the creation of a National Science Foundation was critical to the long-term interests of the Nation. Elmer Staats, his direct supervisor, and Willis Shapley, his BoB colleague, aided him in his crusade.

No doubt the single individual, in addition to Carey, who deserves credit for negotiating the compromise between the scientific community and the Truman Administration and Congress for the creation of a National Science Foundation was Dael Wolfe, at that time executive secretary of the American Psychological Association and also secretary of the AAAS-based Intersociety Committee for a National Science Foundation.

⁶Public Law 81-507, Section 2.

⁷The Korean War began on June 25, 1950 (six weeks after NSF was created), when North Korean troops crossed the 38th parallel into South Korea and within two days captured Seoul.

On the day Truman met with the Board, United Nations' forces abandoned the North Korean capital of Pyongyang, which they had captured in September 1950, and within a few days abandoned Seoul, the South Korean capital, as well. There was justifiable concern that it might not be possible to confine the worsening military situation to Korea. By that time, the White House had already commissioned William T. Golden, a New York investment banker, to prepare a report on how the Nation's scientific resources might be mobilized to address any wider military emergency (Blanpied 1995, xiv–xliv). Whether or not such a wider emergency would occur, it was abundantly clear that both the Congress and the Administration would thenceforth accord a high priority to defense-related research and development (R&D).

Despite the Korean emergency, the NSB adopted a long-term view as it proceeded to work out the policy implications of NSF's charter and develop plans to implement its programmatic mission. At the conclusion of its third meeting on February 13–14, 1951, the Board issued a public statement that disavowed any direct NSF involvement with defense-related research, while reemphasizing that “the fundamental objective of the National Science Foundation is the promotion of basic research and education in the sciences throughout the country.”⁸

On December 18, 1950, less than a week after the first meeting of the NSB, Golden addressed a memorandum to the President recommending that he appoint a full-time science advisor to assist in mobilizing science for defense purposes and, additionally, provide high-level oversight of the entire Federal science organization. President Truman accepted the essence of this recommendation when, on April 19, 1951, he established the Scientific Advisory Committee to the White House Office of Defense Mobilization (SAC/ODM), a body that was destined to evolve into a full-scale presidential scientific advisory system.⁹

With the creation of SAC/ODM, all principal elements of the U.S. Government's science structure were in place, including a protopresidential advisory and coordination system¹⁰ and the six agencies—or their predecessors—that have long accounted for more than 90 percent of Federal R&D expenditures.¹¹ Most changes made in that structure during the next 50 years were designed to adapt it to the evolving

political, economic, and social environment in which the U.S. science and technology enterprise functions and to the spectacular growth of the enterprise itself.

One important refinement in the Federal Government's organization for science and technology was the creation of the Defense Science Board (DSB), which was chartered to “canvass periodically the needs and opportunities presented by new scientific knowledge for radically new weapons systems.” Initially, DSB, which met for the first time on September 20, 1956, was an advisory body to the Assistant Secretary of Defense (Research and Development). During the next few years, as the Defense Department was reorganized to reflect the increasing importance of science and technology to its mission, the status of DSB was elevated to that of an advisory body to the Secretary of Defense. DSB currently consists of 32 members who are appointed for terms ranging from one to four years and selected on the basis of their preeminence in the fields of science and technology and their applications to military operations, research, engineering, manufacturing, and acquisition processes. It also includes the chairs of seven advisory bodies to other Defense Department organizations as *ex officio* members.

Investments

From the outset, the NSB assumed responsibility to gather, analyze, and disseminate quantitative information on the condition of the U.S. science and engineering enterprise. The first *National Science Foundation Annual Report*, covering fiscal year (FY) 1951 (July 1, 1950, to June 30, 1951) and issued under the guidance of the Board, included data estimates from the Department of Defense Research and Development Board on R&D expenditures by the Federal Government and “other” sources, from 1940 through 1952, in addition to data on R&D performance by the industrial, Federal Government, and academic sectors over the same period. It also reproduced more detailed data from the Bureau of the Budget (BoB) on R&D expenditures by the principal Federal agencies from 1940 to 1950.¹² NSF was not represented in the latter tabulation, since it had been created only during the final months of FY 1950, with a budget of \$225,000 to defray administrative startup costs during its first year.

The Foundation's second annual report, covering the period from July 1, 1951, to June 30, 1952, extended the data on Federal R&D expenditures through FY 1952. (See text table 1-2.) NSF was included for the first time, Congress having appropriated an estimated \$1.1 million for R&D expenditures from a total FY 1952 appropriation for NSF of \$3.5 million.¹³ NSF's

⁸References to National Science Board actions during its first meetings are taken from the unpublished minutes of those meetings.

⁹From a letter written by Harry S. Truman, dated April 19, 1951, to Oliver E. Buckley; see Blanpied (1995, 72–4).

¹⁰On November 7, 1957, a month after the Soviet Union launched Sputnik I, President Dwight D. Eisenhower created a full-scale Presidential Advisory System when he elevated SAC/ODM into the President's Science Advisory Committee and named James R. Killian, Jr., president of the Massachusetts Institute of Technology, as his full-time science advisor; see “The Precarious Life of Science in the White House,” by David Z. Beckler (Holton and Blanpied 1976, 118).

¹¹Four of these agencies still exist in their 1951 form: the Department of Defense, NIH (now within the Department of Health and Human Services), NSF, and the U.S. Department of Agriculture. In 1958, as one response to the launching of Sputnik I by the Soviet Union in October 1957, the scope of the National Advisory Committee for Aeronautics, created in 1915, was expanded and the agency renamed the National Aeronautics and Space Administration. AEC was subsumed into the Energy Research and Development Agency in 1975, which in turn was absorbed into the Department of Energy when the latter department was created in 1977.

¹²Prior to 1976, the U.S. Government fiscal year began on July 1 of the succeeding calendar year, rather than on October 1 as it does at present.

¹³In 1945, *Science—The Endless Frontier* (Bush 1945a, 40) had recommended a budget of \$33.5 million for the Foundation's first year, which would have been approximately \$47.1 million in 1951 constant dollars. However, the National Science Foundation Act of 1950 included an amendment limiting the agency's appropriation to \$15 million per year, or approximately \$95 million in constant 1999 dollars. NSB had requested \$13.5 million for NSF for FY 1952; Congress reduced it to \$3.5 million (\$20 million in 1999 constant dollars) on the grounds that the imperatives of the Korean War precluded anything more. The \$15 million limitation was removed in 1953.

Text table 1-2.

Federal R&D appropriations for Fiscal Year 1952

Agency	Amount of U.S. dollars (in millions)		Percent	
	1952 current	1998 constant	Total	Non-DOD
Department of Defense (DOD)	890.0	5,071.6	70.6	
Non-DOD	370.2	2,109.5	29.4	100.0
Atomic Energy Commission	162.9	928.3	12.9	44.0
Public Health Administration ^a	38.5	219.4	3.1	10.4
National Advisory Committee for Aeronautics	49.4	281.5	3.9	13.3
National Science Foundation	1.1	6.3	0.1	0.3
Agriculture Department	51.7	294.6	4.1	14.0
Commerce Department	15.4	87.8	1.2	4.2
Interior Department	31.9	181.8	2.5	8.6
Other	19.3	110.0	1.5	5.2
Total	1,260.2	7,181.1	100.0	

NOTE: Details may not sum to totals because of rounding.

^aIncludes National Institutes of Health.SOURCE: National Science Foundation, *Second Annual Report* (Washington, DC: U.S. Government Printing Office, 1952).

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total budget for that year also included \$1.53 million for graduate and post-doctoral fellowships. The remaining funds were allocated for administration, and for miscellaneous activities, including scientific translations.

Despite the fact that its R&D appropriation for FY 1952 was \$1.1 million, compared with the total Federal R&D budget of more than \$1.2 billion, NSF already occupied a unique position in the Federal system. It was—and remains—the sole agency chartered to support research and education across all fields of science and engineering. In addition, Congress expected NSB, its policymaking body, to deal with issues transcending the Foundation's programmatic mission. Among other things, NSF (by law the National Science Board and Director) was “authorized and directed” to develop and encourage the pursuit of a national policy for the promotion of basic research and education in the sciences; ... to foster the interchange of scientific information among scientists in the United States and foreign countries; and ... to correlate the Foundation's scientific research programs with those undertaken by individuals and by public and private research groups.”¹⁴

The evolution of the Board's involvement in monitoring the state of science and engineering, culminating with the transmission of the first *Indicators* report (NSB 1973) to President Richard M. Nixon in 1973, is discussed in “Monitoring the Condition of the Science and Engineering Enterprise.”

Early Visions/Key Policy Documents

Both the size and complexity of the U.S. science and engineering enterprise have grown substantially since the creation of NSF. Despite this, a striking continuity with the present is discernible in the visions of science–government relations that

emerged in the immediate aftermath of World War II. These early visions were encapsulated in two key policy documents: *Science—The Endless Frontier* (July 1945) and *Science and Public Policy* (August 1947). Although differing in many respects, both reports emphasized the need for a strong commitment to genuine partnerships and linkages among the industrial, academic, and Federal Government research sectors, a commitment that is among the unique strengths of the U.S. system.

Science—The Endless Frontier (1944–45)

The impetus for *Science—The Endless Frontier*, as already noted, was a letter addressed to Vannevar Bush by President Franklin D. Roosevelt on November 17, 1944, 10 days after President Roosevelt's reelection to an unprecedented fourth term. The President's letter asked for advice on how lessons learned from the mobilization of science and engineering during World War II might be used in peacetime “for the improvement of the national health, the creation of new enterprises bringing new jobs, and the betterment of the national standard of living” (Bush 1945a, 3).

Creation of the Office of Scientific Research and Development

That the President would seek guidance on these matters from Vannevar Bush, who was director of the wartime Office of Scientific Research and Development (OSRD) was natural enough, since Bush had been serving as his *de facto* science advisor for more than a year before the United States entered World War II in December 1941. On June 12, 1940, seven days after the German army invaded France, Bush, president of the Carnegie Institution of Washington and a former Dean of Engineering at the Massachusetts Institute of Technology (MIT), met with the President to propose that he should

¹⁴Public Law 81-507, Section 3(a).

create a National Defense Research Council (NDRC). NDRC's charge would be to explore, in detail, the problem of organizing the Nation's scientific resources in preparation for what both men were certain would be the inevitable entry of the United States into what was still primarily a European conflict. Roosevelt accepted this proposal, naming Bush chairman of NDRC.¹⁵

A year later, Roosevelt decided that the rapidly escalating military crisis abroad required the creation of an agency with broader authority than NDRC. Accordingly, in June 28, 1941, he issued an executive order creating OSRD within the Executive Office of the President, stating that OSRD was to:

... serve as a center for mobilization of the scientific personnel and resources of the Nation in order to assure maximum utilization of such personnel and resources in developing and applying the results of scientific research to defense purposes ... [and] to coordinate, aid, where desirable, supplement the experimental and other scientific and medical research activities relating to national defense carried on by the Departments of War and Navy and other departments and agencies of the Federal Government.¹⁶

NDRC, chaired by James B. Conant, was retained as one of two components of OSRD; a Medical Research Committee was created as its other component.¹⁷

OSRD was authorized to mobilize the Nation's science and engineering resources for the impending entry of the United States into World War II. To do so, Bush and his senior colleagues faced the formidable tasks of working with appropriate staff in the Departments of War and Navy to identify and establish priorities for defense-related research projects; identifying and assembling the scientists and engineers capable of dealing with those projects; providing them with the resources they required; and finally ensuring that their results moved expeditiously into wartime production.

The Prewar U.S. R&D Enterprise

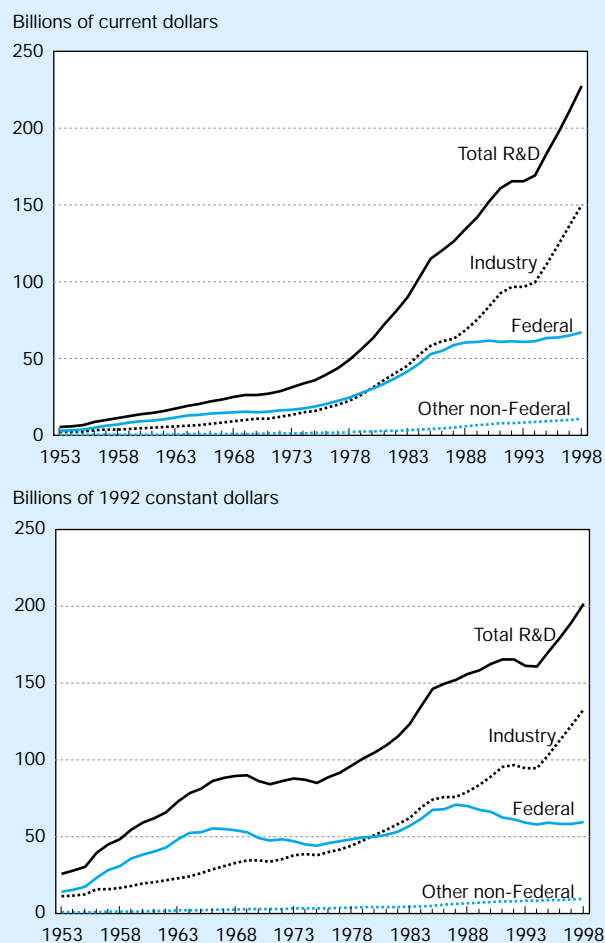
While the science and engineering resources available to OSRD were reasonable, they were also scattered. By 1940, the three sectors that still account for most of the Nation's research performance—industrial, government, and academic—were already well established. However, their relative importance and the relationships between them differed from what they are today. Then as now, industry was the principal supporter and performer of R&D. A total of \$345 million was estimated to have been expended for R&D in the United States in 1940, with industry investing \$234 million,

or almost 68 percent of this amount.¹⁸ Although industrial investments were roughly the same proportion of total national expenditures as at present, from 1951 (the first full year of the Korean War) until 1980, industry's share of total national R&D expenditures was less than that of the Federal Government. (See figure 1-1 and text table 1-3.)

In 1940, the Federal Government ranked a distant second, expending an estimated \$67 million for R&D, or less than 20 percent of total national R&D expenditures, during that same year. In fact, Federal R&D expenditures in 1940 were only slightly more than twice the \$31 million expended by universities and colleges. The remaining \$13 million was accounted for by state governments, private foundations and research institutes, and nonprofit industrial research institutes. No reliable prewar data are available on R&D performance expenditures. However, it is reasonable to assume that the bulk of the industrial and Federal Government expenditures went to

¹⁸R&D expenditure estimates are given by Bush (1945a, app. 3, 86) and Steelman (1947, vol. I, 10).

Figure 1-1.
National R&D funding, by source: 1953–98



See appendix tables 2-5 and 2-6.

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¹⁵Other NDRC members included James B. Conant, president of Harvard University (and later the first chairman of NSB); Karl T. Compton, president of MIT; and Frank B. Jewett, president of the National Academy of Sciences and chairman of the board of the Bell Telephone Laboratories.

¹⁶Executive Order 8807, "Establishing the Office of Scientific Research and Development in the Executive Office of the President and Defining Its Functions and Duties."

¹⁷When OSRD was abolished at the end of 1947, the contracts that its Medical Research Committee still retained with several of the Nation's medical schools were turned over to NIH. These transfers initiated the transition of NIH from an agency that had previously supported research primarily in its own laboratories, to one of the world's foremost supporters of biomedically related research, as well as the Federal agency with the largest basic research budget.

Text table 1-3.

Estimated R&D expenditures, by source for selected years

Expenditures (in millions)	Total	Industry	Federal	Universities and colleges	Other ^a
1940 current dollars	345	234	67	31	13
1998 constant dollars	3,617	2,453	702	325	136
Percent of total	100	67.8	19.4	9.0	3.8
1947 current dollars	1,160	450	625	45	40
1998 constant dollars	7,645	2,966	4,119	297	264
Percent of total	100	38.8	53.9	3.9	3.4
1957 current dollars	9,908	3,470	6,233	51	155
1998 constant dollars	50,345	17,629	31,669	259	788
Percent of total	100	35.0	62.9	0.5	1.6
1967 current dollars	23,346	8,146	14,563	200	439
1998 constant dollars	99,326	34,655	61,957	849	1,866
Percent of total	100	34.9	62.4	0.9	1.9
1977 current dollars	43,456	19,645	22,155	569	1,089
1998 constant dollars	103,258	46,678	52,642	1,351	2,586
Percent of total	100	45.2	51.0	1.3	2.5
1987 current dollars	126,255	62,683	58,548	2,262	2,762
1998 constant dollars	171,309	85,052	79,441	3,069	3,747
Percent of total	100	49.6	46.4	1.8	2.2
1998 current dollars	227,173	149,653	66,930	4,979	5,611
Percent of total	100	65.9	29.5	2.2	2.5

NOTE: Details may not sum to totals because of rounding.

^aIncludes state governments and nonprofit institutions.

SOURCES: For 1940, Vannevar Bush, *Science—The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research* (1945a). Reprinted by NSF (Washington, DC: 1990). For 1947, John R. Steelman, *Science and Public Policy* (Washington, DC: U.S. Government Printing Office, 1947). Reprinted by Arno Press (New York: 1980). For 1957–98, National Science Foundation, *National Patterns of R&D Resources*. (Arlington, VA: biennial series).

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support R&D in their own respective facilities, whereas all academic expenditures for this purpose supported academic research.

Despite the absence of reliable data, it is widely acknowledged that a good deal of academic research prior to World War II qualified as applied research according to current definitions. Additionally, academic research, whether basic or applied, was concentrated in a relatively small number of institutions. According to *Science—The Endless Frontier*, during the 1939/40 academic year, 10 of the estimated 150 research universities in the United States performed \$9.3 million or 35 percent of the total \$26.2 million in research performed in the natural sciences and engineering by the academic sector, while 35 of these 150 universities performed \$16.6 million or 63 percent of the academic total (Bush 1945a, 122).

Prior to World War II, institutional partnerships among the Nation's three research sectors were the exception rather than the rule. Department of Agriculture programs that had supported research in the Nation's land grant colleges since the late 19th century constituted one prominent set of exceptions. Precedents set by the National Advisory Committee on Aeronautics (NACA), the predecessor of the National Aeronautics and Space Administration (NASA), were more pertinent to the OSRD system. NACA, which was created in 1915 and

consisted of representatives from both the Federal Government¹⁹ and industry, operated facilities that conducted R&D related to problems of civil and military aviation. The bulk of NACA's research was conducted in these in-house facilities, which were taken over by NASA when the latter agency was created in 1958. However, during the 1920s, NACA also began to award occasional contracts to university engineering schools. In 1939, it had 12 contracts with 10 universities (Dupree 1957, 366).

With these exceptions, the Federal Government provided no support for university research prior to 1941. Faculty in university science and engineering departments occasionally worked in their private capacities as consultants to Federal research bureaus. But any suggestion that the Federal Government should initiate an openly available program to fund university research on no grounds other than its intrinsic merit would have been considered an unwarranted intrusion into the affairs of those institutions. Rather, research in the academic sector was supported by income on endowment (in the case of private universities); by state funds (in the case of public universities); by grants from private, nonprofit foundations such as the Carnegie Corporation, the Rockefeller

¹⁹One of the original Federal Government members of NACA was Franklin D. Roosevelt, then serving as Assistant Secretary of the Navy in the Wilson Administration.

Foundation, and the Commonwealth Fund; and on occasion by private industry.

The OSRD System

The OSRD system was collegial and decentralized. Rather than electing to become a scientific “czar” who would centralize and control all aspects of the wartime research effort, Bush assumed the roles of buffer and arbitrator between the scientists and engineers engaged in wartime research and the Federal Government’s technical bureaus, particularly those in the Departments of War and Navy. During World War I, many of the scientists and engineers who had engaged in defense research were given temporary military commissions, then sent to work at existing defense laboratories (Dupree 1957, 302–25). In contrast, the OSRD system was based on the novel assumption that, except in very special cases, research could best serve wartime needs if scientists and engineers continued in their civilian status and worked in settings where research was carried out in peacetime—be they academic or industrial. That is, industrial and academic organizations worked in partnership with the Federal Government rather than under its direct control. Because Bush enjoyed direct access to President Roosevelt, he was able to convince him (although not all the old line Federal scientific bureaus) that this decentralized system would be more effective in achieving the desired result of adapting U.S. scientific resources rapidly for national defense purposes than a system based on the World War I model.

In fact, the system was superbly effective. Radar was developed and refined at the Radiation Laboratory at MIT by scientists and engineers brought there from several institutions. The Oak Ridge, Tennessee, facility, where the rare, fissionable isotope of uranium ($^{235}\text{U}_{92}$) was separated, was managed by the General Electric Company. Even the ultra-secret Los Alamos, New Mexico, laboratory, where the R&D leading to the first nuclear bombs was performed, was managed by the University of California under a contract with the Army rather than directly by the Federal Government.

Following its creation in 1946, AEC took over from the Army its management contracts with the General Electric Company, the University of California, and several other organizations that had managed these World War II facilities, and the facilities themselves came to be known as Federally funded research and development centers (FFRDCs). Many are still managed by the same academic or industrial organization that managed them during World War II through contracts with the Department of Energy. Additional FFRDCs have been created since World War II, some of which, such as the Fermi National Accelerator Laboratory in Batavia, Illinois, and the Stanford Linear Accelerator Center (SLAC), house large-scale facilities where basic research is conducted by university-based user groups.²⁰

²⁰Other agencies, including the Department of Defense and NASA, also support FFRDCs through contracts with nongovernment organizations; cf. NSB (1996a, 4-26–4-29).

Wartime experiences had demonstrated the potential for productive partnerships among the Nation’s principal research sectors. They also demonstrated the importance of university scientists (and thus, by implication, the academic sector) in conceptualizing and demonstrating the feasibility of novel, often risky research ideas—such as many of the concepts underlying radar and nuclear weapons. Additionally, they suggested that, even in wartime, the effective conduct of research required that science be insulated, as much as possible, from conventional political processes. These experiences conditioned the vision articulated by *Science—The Endless Frontier*.

Responding to Roosevelt

President Roosevelt’s November 1944 letter to Bush on the peacetime implications of lessons learned from the World War II mobilization of science and engineering requested responses to four questions. These questions dealt with (1) the expeditious declassification of secret wartime research results, (2) the need to develop a program to support health-related research, (3) conditions through which the government could provide aid to research activities in public and private organizations, and (4) the feasibility of creating a program for discovering and developing scientific talent. To address the President’s request, Bush convened four committees consisting primarily of distinguished nongovernment scientists and engineers, charging each committee to prepare a report, with recommendations, on one of President Roosevelt’s four questions.²¹ Bush’s own 40-page synthesis of the resulting committee reports constituted the body of *Science—The Endless Frontier* (Bush 1945a); the four committee reports, each consisting of an in-depth response to one of the President’s questions, appeared as appendices.

Bush and his committees carried out their assigned tasks during months of mounting exuberance. By the time *Science—The Endless Frontier* was submitted to President Truman in July 1945, World War II was drawing rapidly to a close. Germany had surrendered on May 8, the first nuclear weapon was due to be tested on July 16, and the defeat of Japan was all but assured—even though informed military opinion estimated that another year and as many as 1 million American casualties would be required. The United States and its allies had achieved military supremacy, and science and engineering had made indispensable contributions to that outcome.

Bush and his colleagues welcomed the opportunity to take the lead in planning for the future and, in particular, to capitalize on the recognition that the importance of academic research had received in the OSRD system. However, they insisted that any government program to organize science for peacetime purposes had to be consistent with the traditional norm of scientific autonomy that, to a remarkable extent, had

²¹These were the Medical Advisory Committee, chaired by W.W. Palmer, Bard Professor of Medicine, Columbia University; the Committee on Science and the Public Welfare, chaired by Isaiah Bowman, president of The Johns Hopkins University; the Committee on Discovery and Development of Scientific Talent, chaired by Henry Allen Moe, secretary-general of the Guggenheim Foundation; and the Committee on Publication of Scientific Information, chaired by Irvin Stewart, executive assistant to the director of OSRD and later president of the University of West Virginia.

remained largely intact during the wartime years (Reingold 1987; Blanpied 1998).

A National Research Foundation

Bush and his four committees seized the opportunity provided by President Roosevelt's November 1944 letter to advance what could only be regarded at that time as a bold and innovative proposition. Simply stated, *Science—The Endless Frontier* argued that the Federal Government had not only the authority, but also the *responsibility*, to ensure a continued supply of research results by (1) supporting research in nonprofit institutions—primarily, although not exclusively, basic research in universities—and (2) offering scholarships and fellowships to aspiring scientists and engineers.²² An essential element of the report's proposition that the Federal Government should support research in nonprofit organizations was its insistence that the support should be provided solely on the basis of scientific merit, as judged by those with the necessary professional experience and background to make that determination. "It is my judgment," Bush wrote, "that the national interest in scientific research and scientific education can best be promoted by the creation of a National Research Foundation" (Bush 1945a, 34).²³ The new responsibilities envisioned for the Federal Government were too novel and too important to be entrusted to any existing agency. The final paragraph of *Science—The Endless Frontier* stressed that early action by Congress to create the National Research Foundation was "imperative" (Bush 1945a, 40).

In keeping with his wartime experiences, Bush recommended that the new agency should be isolated as much as possible from conventional political processes. Its board of directors (or what *Science—The Endless Frontier* referred to as its "members") would be appointed by the President and would consist of "citizens selected only on the basis of their interest in and capacity to promote the work of the agency. They should be persons of broad interest in and understanding of the peculiarities of scientific research and education" (Bush 1945a, 33). The National Science Foundation Act of 1950 adhered to this dictum by legally defining NSF as a Director and a National Science Board to consist of 24 members "eminent in the fields of basic sciences, medical science, engineering, agriculture, education, and public affairs."²⁴

Promotion of Research in Industry

The line of reasoning that *Science—The Endless Frontier* presented in arriving at its centerpiece recommendation is worth reviewing, since it was to become a major foundation of U.S. science policy for many years. In keeping their own *laissez-faire*, free-market philosophy, Bush and his colleagues were adamantly opposed to any Federal Government inter-

ference with the prerogatives of private industry, except in the area of national defense. Industry alone, they argued, was equipped to determine which basic research results in the public domain were worth exploiting for possible commercial purposes and how they should be exploited. This position was summarized in a familiar passage from *Science—The Endless Frontier*, namely, that "The most important ways in which the Government can promote industrial research are to increase the flow of new scientific knowledge through support of basic research, and to aid in the development of scientific talent" (Bush 1945a, 7).

Prior to World War II, the large majority of the basic research results that industry required were foreign imports, primarily from Europe. But European research capabilities had been devastated by World War II. Therefore, the Bush report argued, the United States would henceforth have to assume primary responsibility for obtaining its own basic research results.

Centrality of Universities

Science—The Endless Frontier's central proposition that Federal science policy should focus on the support of research in nonprofit institutions (mainly colleges and universities) strongly if implicitly suggested that universities, which prior to World War II were on the periphery of the U.S. research system, should be thenceforth regarded as occupying its vital center. This line of argument was persuasive; much of the most innovative wartime research had been carried out in university or quasi-university settings by university scientists and engineers. With the partial exception of the United Kingdom, no other country had had a similar experience. As one result, the postwar emergence of universities as the primary performers of basic research has been virtually unique to the United States.

Other Issues

Science—The Endless Frontier was never intended to be a complete blueprint for U.S. science policy. In fact, much of its enduring impact is explained by the fact that it focused on a few key ideas and advanced them persuasively. The most enduring of those ideas are in the category that would later be referred to as "policy-for-science": that is, issues having to do with funding levels, sources, incentives, and priorities for research, and the development and utilization of human resources for science and engineering, for example.

In contrast, considerably less attention was paid to issues in the "science-for-policy" category—those concerned with the uses of scientific knowledge and capabilities for governance or, more broadly, in the service of the larger society. *Science—The Endless Frontier* did recognize the vital importance of science to society; its opening paragraphs state emphatically that "without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world" (Bush 1945a, 5). Additionally, adequate responses to President Roosevelt's queries, such as declassification of wartime re-

²²Bush was familiar with the legislation to create a National Science Foundation that had been introduced by Senator Kilgore in 1944, which was a revised version of an earlier 1943 bill. In fact, Kilgore had sought Bush's advice on certain aspects of its revision (Kevles 1977).

²³Soon after the start of congressional hearings in October 1945, the name National Science Foundation rather than National Research Foundation was adopted for the proposed agency. See England (1983).

²⁴Public Law 81-507, Section 4(a).

search results, required specific science-for-policy recommendations. Finally, the report stressed the desirability to “coordinate where possible research programs of utmost importance to the national welfare” (Bush 1945a, 31), but offered few hints on how that might be accomplished other than through a nongovernmental oversight and advisory committee.

Several of these themes and issues considered by *Science—The Endless Frontier*, such as those that addressed the President’s first question on the declassification of wartime research results, are now of little interest save to students of the postwar period. Others retain their currency, even though their context has changed considerably. These include the following:

- ♦ integration of defense research into the overall national system,
- ♦ human resources for science and engineering,
- ♦ research in Federal mission agencies,
- ♦ tax and patent policies, and
- ♦ international exchange of scientific information.

These and other issues were also treated, often at greater length, in *Science and Public Policy*—which was intended to be both a policy-for-science and science-for-policy document—when it was prepared beginning in late 1946. They are thus identifiable as among the principal science policy themes during the first time of transition, as discussed below.

Use of Data

Although Bush included an occasional quantitative reference in the body of *Science—The Endless Frontier*, he relied almost entirely on his wide experience and his persuasive rhetoric, rather than on data-based analysis, to press his case for a National Research Foundation. The four appended committee reports relied more heavily on data. They included, for example, tables listing national research expenditures from 1920 to 1944 and details of research expenditures in selected university departments and companies (Bush 1945a, 123, 127–9). Human resources data included numbers of Ph.D.s awarded by the scientific field from 1935 (Bush 1945a, 177–9). Several related tables, referred to, collectively, as the education pyramid, provided data on enrollments in educational institutions from primary grades through college and graduate school for all students, but with no breakdown for enrollments in science (Bush 1945a, 166–76). These data provided a basis for arguing that too many otherwise able students were being lost to higher education because of their inability to pay the required costs so that the provision of Federal Government-supported scholarships and fellowships, based on academic promise, would be in the national interest.

That the bulk of the data contained in the committee reports predated 1941 provides a clue to why *Science—The Endless Frontier* contained relatively little quantitative information: namely, the wartime conditions prevailing in 1944–45 precluded the provision of the resources that would have

been necessary to conduct the studies that would have been needed to obtain a more detailed, quantitative picture of the U.S. science and engineering enterprise. Additionally, financial and human resources data considered critical to national mobilization would almost certainly have been classified. After the war ended, it was possible once again to collect and/or declassify data on various aspects of U.S. society, including those related to science and engineering. Many of these categories of data were compiled and analyzed in the August 1947 report of the President’s Scientific Review Board entitled *Science and Public Policy* (Steelman 1947).

Science and Public Policy (1946–47)

Context

In November 1944 when President Roosevelt addressed his four questions to Vannevar Bush, only he and a handful of OSRD colleagues, a few members of Congress and their key staff, along with several officials in BoB, had given much serious thought to issues of science and government in the postwar era (Kevles 1977). Within the next two years, the rapidly increasing significance of the Federal Government’s role in science and engineering had become obvious, as had the impact of Federal policies and actions on the industrial and academic research sectors.

Given the pervasive character of the Federal role, the BoB had become convinced by the end of 1945 that it required an institutionalized source of expert advice to assist it in its task of formulating and implementing science- and technology-related policies and programs. It believed that what by then was being referred to as a National Science Foundation, particularly what a pending congressional bill proposed as its governing board of eminent nongovernment presidential appointees, could provide the advice it required.

However, although the general idea of an agency to support research in nonprofit organizations, provide scholarships and fellowships, and serve as a source of policy advice attracted bipartisan congressional support, there were serious differences within the Congress and between the Congress and the Truman Administration on specific details, including the scope and administrative structure of the proposed agency. When, in June 1946, the 79th Congress adjourned before the House of Representatives had considered a Senate bill to create a National Science Foundation,²⁵ several BoB staff members, including Elmer Staats, William Carey, Willis Shapley, and Charles Kidd, began to explore other options to carry out the functions they had hoped a National Science Foundation and its Board would fulfill. Accordingly, they persuaded President Truman to issue an Executive Order on October 17, 1946, to create a President’s Scientific Research Board charged “to review current and proposed research and development (R&D) activities both within and outside of the Federal Government.”

²⁵The failure of the 1946 legislation was the first of several failed attempts to reconcile conflicting views on the organization of the proposed agency that were to delay enactment of enabling legislation until May 1950 (England 1983, Blanpied 1998).

PSRB was chaired by John R. Steelman, director of the Office of War Mobilization and Reconversion within the Executive Office of the President, who on January 1, 1947, was appointed the Assistant to the President. Steelman, an economist who had helped settle two potentially crippling labor disputes early in 1946, enjoyed the confidence of, and ready access to, President Truman. Among his other duties, he oversaw and coordinated the work of the White House staff so that he became, in effect, the first White House Chief of Staff.²⁶

Scope and Content

The President's Executive Order had charged Steelman, as PSRB chairman, to submit a report:

... setting forth (1) his findings with respect to the Federal research programs and his recommendations for providing coordination and improved efficiency therein; and (2) his findings with respect to non-Federal research and development activities and training facilities ... to insure that the scientific personnel, training, and research facilities of the Nation are used most effectively in the national interest.²⁷

The first volume of the PSRB's report, entitled *Science and Public Policy* and commonly referred to as the Steelman report, was published on August 27, 1947. Consistent with the President's charge, the report balanced considerations of policy-for-science and science-for-policy. The analysis, conclusions, and recommendations contained in the first 68-page summary volume, aptly entitled "A Program for the Nation," spanned the entire range of Federal and non-Federal science and technology activities, including the international dimensions of U.S. science policy. Much of the text was supplemented with imaginative graphics, which were used to support its arguments, conclusions, and recommendations. These were based on detailed, extensive data and analysis contained in the report's four succeeding volumes, all of which were released by the end of October 1947.²⁸

Taken together, the Steelman report's five volumes compose what was by far the most complete and detailed description of the U.S. science and technology system (particularly its Federal component) that had been produced up to that time. The four background volumes of *Science and Public Policy*, in their extensive use of data and survey results (a good deal gathered specifically for the report), their analyses, and their use of charts, can be regarded as a precursor for what was to become, beginning in 1972, NSB's biennial series of *Science and Engineering Indicators* reports.

²⁶Members of PSRB included the secretaries of all cabinet departments with significant science and technology programs, including War, Navy, Agriculture, Commerce, and Interior, as well as the heads of several noncabinet agencies, including NACA (the precursor of NASA), AEC, the Tennessee Valley Authority, the Veterans Administration, and importantly, Vannevar Bush as director of OSRD.

²⁷Executive Order 9791, "Providing for a Study of Scientific Research and Development Activities and Establishing the President's Scientific Research Board" (Stelman 1947, vol. I, 70–1).

²⁸The titles of the five volumes of *Science and Public Policy* (the Steelman report) were vol. I, "A Program for the Nation"; vol. II, "Science in the Federal Government"; vol. III, "Administration of Research"; vol. IV, "Manpower for Research"; and vol. V, "The Nation's Medical Research."

Themes and Issues

Research Expenditures

A unique feature of "A Program for the Nation," the first summary volume of *Science and Public Policy*, was its use of 10-year projections, or scenarios, to support its recommendations regarding the resources required by the U.S. science and engineering enterprise to provide it an adequate basis to assist in addressing national objectives. Perhaps its most significant projection was in the form of a recommendation to double national R&D expenditures during the succeeding 10 years, that is, by 1957 (Stelman 1947, vol. I, 13, 26). In 1947, total U.S. R&D expenditures were estimated to be slightly more than \$1 billion. (See text table 1-4.) According to this scenario, national R&D expenditures should reach an annual level of \$2 billion—or 1 percent of national income (that is, Gross Domestic Product, GDP)—by 1957, requiring greater increases in public than in private spending.

The report went on to recommend explicit functional targets for Federal R&D expenditures to be achieved by 1957: 20 percent for basic research, 14 percent for research in health and medicine, 44 percent for nonmilitary development, and 22 percent for military development (Stelman 1947, 28).

Basic Research Support

Basic research was singled out as the principal arena for concerted Federal action by both *Science—The Endless Frontier* and *Science and Public Policy*. Both reports urged Con-

Text table 1-4.
Estimated 1947 U.S. R&D expenditure,
by source and character of work

Source	Total	Basic research	Applied R&D
1947 current dollars (in millions)			
Federal Government			
War and Navy departments ..	500	35	465
Other departments	125	20	105
Federal total	625	55	570
Industry	450	10	440
University	45	35	10
Other	40	10	30
U.S. total	1,160	110	1,050
1998 constant dollars (in millions)			
Federal Government			
War and Navy departments ..	3,295	231	3,065
Other departments	824	132	692
Federal total	4,119	362	3,757
Industry	2,966	66	2,900
University	297	231	66
Other	264	66	198
U.S. total	7,645	725	6,920

NOTE: Details may not sum to totals because of rounding.

Applied R&D = Applied Research and Development

SOURCE: John R. Steelman, *Science and Public Policy* (Washington, DC: U.S. Government Printing Office, 1947). Reprinted by Arno Press (New York: 1980). *Science & Engineering Indicators – 2000*

gress to enact legislation to create a National Science Foundation; the latter recommended that the proposed agency should be authorized “to spend \$50 million in support of basic research its first year ... rising to an annual rate of \$250 million by 1957” (Steelman 1947, 31–2).

Defense Research

OSRD’s wartime achievements were based in large measure on the active participation of nongovernment civilian scientists and engineers in all aspects of military R&D, from planning through implementation. Vannevar Bush was determined to maintain civilian involvement, and in some cases even civilian control, over the most critical defense-related research projects in the postwar era. “Military preparedness,” as *Science—The Endless Frontier* argued, “requires a permanent, independent, civilian-controlled organization, having close liaison with the Army and Navy, but with funds direct from Congress and the clear power to initiate military research which will supplement and strengthen that carried on directly under the control of the Army and Navy” (Bush 1945a, 33). That is, Bush took the position that defense research policy should be an integral component of overall Federal research policy.

By August 1947, a special task force of the Defense Research Board (which Bush chaired) in the newly created Department of Defense was preparing its own report and recommendations so that the Steelman Board excluded itself from any detailed examination of defense research, other than to recommend that more weight should be given to nondefense research than was the case in 1947.²⁹

Human Resources for Science and Engineering

The development of scientific talent was of particular concern in the late 1940s. World War II had demonstrated that the availability of adequate numbers of well-trained scientists and engineers, rather than a lack of financial resources, was the limiting factor in undertaking or completing essential research projects. The war itself had led to what both reports referred to as a severe “deficit” in trained scientists and engineers resulting from the fact that young people who would have obtained degrees in science and engineering had been prevented from doing so as a result of their service in the Armed Forces. Many trained scientists and engineers had also been among the casualties of the war. *Science and Public Policy* emphasized that, unless and until these deficits were corrected, the U.S. research enterprise could not use significant additional funding to maximum advantage.

In 1947, there were an estimated 137,000 scientists, engi-

neers, and technicians engaged in R&D and/or teaching. Among these, 25,000 had Ph.D.s in the physical and biological sciences (Steelman 1947, vol. I, 15–8). During 1941, the number of Ph.D.s awarded in the physical and biological sciences had reached a peak level of 1,900. By comparison, fewer than 800 Ph.D.s were awarded in these fields during 1945. Although the number of Ph.D.s awarded had risen to approximately 1,600 by 1947, *Science and Public Policy* estimated that the rate of Ph.D. conferrals in science would have to increase to 3,800 per year by 1957 to provide adequate human resources for the Nation.

Both *Science—The Endless Frontier* and *Science and Public Policy* recommended that the Federal Government should support a substantial program of scholarships at the undergraduate level and fellowships at the graduate level to alleviate these human resource deficits. *Science and Public Policy* argued that Federal aid should not be limited to students in science and engineering. Rather, it should be part of a more extensive Federal Government program designed, in part, to relieve wartime deficits in other areas as well.

Science and Public Policy emphasized that the condition of science education at the primary and secondary levels was an essential determinant of the health of the U.S. science and engineering enterprise. Volume IV, devoted entirely to human resources issues, included an analysis of the results of an extensive survey, entitled “The Present Effectiveness of Our Schools in the Training of Scientists,” commissioned from AAAS (Steelman 1947, 47–162). The AAAS report dealt with the entire mathematics, science, and engineering education system from the primary grades through graduate school.

Science and Public Policy also recognized that the working conditions of scientists and engineers could have a decided impact on their productivity and, therefore, on the condition of the U.S. research enterprise. Accordingly, it commissioned a detailed survey on attitudes of government, industry, and academic scientists toward their work from the National Opinion Research Center at the University of Denver (Steelman 1947, vol. III, 205–52).

Role of the Federal Government

World War II having ended, it was generally agreed that the bulk of the Nation’s R&D performance would once again—indeed should once again—take place outside of the government. On the other hand, it was increasingly clear that the Federal Government’s role in the national R&D enterprise had become indispensable. There was a broad consensus that its direct role should include support for research in its own laboratories, provision of funds for basic research in universities and for university facilities, and a scholarship and fellowship program for promising young scientists and engineers. Additionally, the Federal Government should monitor the condition of science and technology in the country and seek means to encourage partnerships among the industrial, academic, and Federal Government research sectors to meet essential national goals. There was much less unanimity on the extent to which the Federal Government should be involved

²⁹The task force, chaired by Irvin Stewart, formerly executive assistant to the director of OSRD and at that time president of the University of West Virginia, issued its report, entitled *Plans for Mobilizing Science*, in 1948. Because of objections by high level Pentagon officials, it did not reach President Truman’s desk until shortly before the start of the Korean War. One of the charges to William T. Golden as special consultant to the White House was to determine the applicability of the Stewart report in the environment of the Korean War.

in the support of nondefense applied research or civilian development.

Internal Government Coordination

Consistent with President Truman's charge in establishing PSRB, *Science and Public Policy* documented in detail the Federal Government's rapidly expanding science and technology programs, noting that they were dispersed across many agencies with little or no coordination among them, except by means of the annual budget process managed by BoB. As one means to improve this situation, it recommended that an interagency committee should be established "to secure maximum interchange of information with respect to the content of research and development programs" and that the Federal Government's role with respect to the national science and technology enterprise should be monitored continually to obtain "an over-all picture of the allocations of research and development functions among the Federal agencies" (Steelman 1947, vol. I, 61).

The report went on to emphasize that science policy issues might often require attention at the highest levels of government. Accordingly, it asserted that "There must be a single point close to the President at which the most significant problems created in the research and development program of the Nation as a whole can be brought into top policy discussions" (Steelman 1947, vol. I, 61).

International Dimensions

The U.S. scientific community was eager to reestablish international communication and information exchange that had been disrupted by World War II. Types of Federal assistance suggested by *Science—The Endless Frontier* and *Science and Public Policy* included funding travel to international scientific meetings, encouraging visits to the United States by outstanding foreign scientists, supporting translations of foreign journals, and awarding international fellowships. *Science and Public Policy* predicted that "the future is certain to confront us with competition from other national economies of a sort we have not hitherto had to meet" (Steelman 1947, vol. I, 4). Despite this, it went on to argue that it was in the national interest to lend "every possible aid to the re-establishment of productive conditions of scientific research and development in all those countries [of Europe and Asia] willing to enter whole-heartedly into cooperation with us" (Steelman 1947, vol. I, 5). The report suggested that such aid might include assistance in the reconstruction of research facilities in Europe as a component of the Marshall Plan, which had been proposed two months before its release.³⁰ It also suggested several more modest measures, including international fellowships for U.S. science and engineering students and more experienced investigators to work abroad, and a program for shorter term visits by senior U.S. researchers to allow them to reestablish international connections interrupted

by World War II. Reciprocally, it recommended that U.S. universities should be encouraged to admit qualified foreign science and engineering students, particularly into their graduate programs (Steelman 1947, vol. I, 38–40).

Looking into the future and beyond the principal prewar scientific powers, the Steelman report noted that:

Currently great progress is being made in India in the construction of new scientific research laboratories and in the training of hundreds of first-rate research workers.³¹ In the same way Chinese scientific development may be expected to go forward rapidly, and great progress is being made in our neighbor American Republics (Steelman 1947, vol. I, 41).

In short, *Science and Public Policy* took the view that U.S. science policy should be based on a long-term view, particularly with regard to its international dimensions, and that what it tacitly assumed would be short-term problems in other countries should not be allowed to obscure the rising importance of science on a global level.

Monitoring the Condition of the Science and Engineering Enterprise

"A Program for the National Science Foundation"

Science—The Endless Frontier and *Science and Public Policy* had both envisioned a science policy implemented in a genuine peacetime context, albeit with due regard for national security needs. As it happened, the final elements of the U.S. Government's science and technology organization were put in place during the early stages of the Cold War. NSF was created barely six weeks before the start of the Korean War on June 25, 1950, and the first protopresidential Science Advisory Committee, established on April 19, 1951, was created as a response to the Korean crisis on the recommendation of William T. Golden.

As background for the report on science and national security that the White House commissioned in September 1950, Golden interviewed a wide range of scientists, military experts, and politicians, including Bush, Steelman, and three prominent scientists whom President Truman had nominated as members of the first NSB on November 2, 1950: Detlev W. Bronk, a biologist who was president of The Johns Hopkins University and of the National Academy of Sciences (NAS); James B. Conant, a chemist and president of Harvard University; and Lee A. DuBridge, a physicist and president of the California Institute of Technology.

While the main purpose of Golden's interviews was to determine whether in view of the Korean crisis an organization similar to OSRD should be created, he frequently inquired as well about the role that the newly created NSF should play among other agencies of the Federal Government. Golden summarized his conclusions in a February 13, 1951, memo-

³⁰Secretary of State George C. Marshall announced the intention of the United States to provide funds for the reconstruction of Europe's infrastructure in an address at the Harvard University commencement on June 7, 1947.

³¹The first volume of the Steelman report was released less than two weeks after India achieved its independence from Great Britain on August 15, 1947.

randum entitled “Program for the National Science Foundation” (Blanpied 1995, 67–72).

Near the beginning of his memorandum, Golden noted that, as a result of the Korean emergency, “Federal funds for research and development of all kinds within the Department of Defense alone, which originally approximated \$500 million for FY 1950, are expected to be in the neighborhood of \$1,250,000,000 for FY 1952.”

It would be tempting, he conceded, for the newly created NSF (which, at the time Golden wrote his memorandum still did not have a director³²) to attempt to capitalize on this situation. However, he went on, “it may be worth repeating that in accordance with the spirit of the Act [of May 10, 1950] the National Science Foundation should confine its activities to furthering basic scientific studies and that it should not dilute its effectiveness by supporting studies of directly military or other applied character. To do so would seriously impair the long-term mission of the National Science Foundation without materially contributing to the war effort.”

Consistent with this long-term view and the high probability that NSF’s financial resources would very likely be constrained at least as long as the Korean emergency continued, Golden suggested that a high priority should be assigned to human resources development in the form of a fellowship program. “In view of the disruption of the educational process inherent in the mobilization effort it would be unwise not to undertake some such fellowship program in order to insure the continuing production of scientific leaders over the longer term ... The cost of such a fellowship program is very small in relation to its potential value and to the total cost of Government’s scientific research program.”

More broadly, and with the long-term mission of NSF still in view, Golden recommended that steps should be taken to assess the status of the Nation’s science and technology system as a first step in determining the agency’s future directions. In essence, he suggested that the Foundation, under the guidance of the Board, should prepare to engage in serious priority-setting based on sound data. To this end, Golden recommended that “the Foundation, promptly after the appointment of a Director, might proceed to the following principal undertakings”:

1. Prepare a comprehensive review detailing the significant areas of basic science which are now being studied within the United States, showing these separately for research supported by universities, by industry and by the Government. To the extent practicable the pattern should also indicate work in process in friendly foreign countries.
2. Prepare a comparable survey detailing the existing support of graduate and undergraduate education in the sciences by the many public and private agencies so engaged.
3. Study the scientific manpower resources of the United States: a) as specifically called for in the Act, by taking over, completing, and keeping current the detailed National

Scientific Register³³; and b) by preparing quantitative analytical studies of available and prospective scientific and technical manpower.

4. Review basic research activities of other Government agencies and in cooperation with them develop proposals for transferring appropriate portions of these programs to the National Science Foundation. In this connection, and to provide background for its work, the Board might wish to invite other Government agencies engaged in or supporting basic research activities to make descriptive presentations of their programs to the Board.

Golden concluded his February 13 memorandum by observing that “preparations of studies of the aforementioned character are primarily tasks for the staff under the Director but the members of the 24-man Board ... are particularly well qualified to plan and determine their undertakings and to give guidance to the staff in the areas of their specialties.”

The director of BoB transmitted Golden’s memorandum to James B. Conant, chairman of the NSB, on February 15, 1951. The minutes of the Board’s fourth meeting, held on March 8–9, 1951, stated that Golden’s memorandum had been received, but that no specific action was taken on it. This is not surprising, since the Board had to deal with a particularly full agenda for that meeting. Its principal business was to finalize and approve the Foundation’s budget request to Congress for FY 1952. Also, on the first day of the meeting, the Board was informed of President Truman’s intention to nominate Alan T. Waterman, chief scientist at ONR, as the NSF’s first director (England 1983, 126–7). The nominee joined the Board on the second day of its meeting. The Senate consented to Waterman’s nomination later that month, and on April 6, 1951, he was sworn in as NSF director by Supreme Court Associate Justice William O. Douglas.

Congressional and Presidential Directives

Despite the fact that the NSB took no direct action on Golden’s memorandum at its March 8–9, 1951, meeting, his suggestion that the policy-for-science of the U.S. Government and the programs of NSF should be based on sound quantitative information was widely shared. In addition to reproducing BoB data on R&D expenditures by Federal agency in its FY 1951 Annual Report, the agency began to publish its *Federal Funds for Research and Development* series during that same fiscal year. Data in the first editions in this series were limited to Federal funds for R&D in nonprofit institutions. However, the coverage expanded to include Federal R&D support in all categories of performer and was also reported by character of work, by field of science, and by agency.

Congress was particularly concerned about the adequacy of human resources for science and technology. The National

³²President Truman announced his intention to nominate Alan T. Waterman as NSF’s first director on March 8, 1951.

³³The National Scientific Register was established in the Office of Education within the Federal Security Agency in June 1950 following a determination by the National Security Resources Board that a registry of available scientific personnel would be vital to national security. It was transferred to NSF on January 1, 1953.

Science Foundation Act of 1950 explicitly directed the agency “to maintain a register of scientific and technical personnel and in other ways provide a central clearinghouse for information covering all scientific and technical personnel in the United States, including its Territories and possessions.”³⁴

To carry out this mandate, NSF assumed responsibility for the National Scientific Register from the U.S. Office of Education on January 1, 1953,³⁵ expanding its coverage significantly in partnership with several science and engineering societies. NSF’s third annual report, covering the period from July 1, 1952, to June 30, 1953, included the first survey results on human resources for science and engineering carried out in response to this congressional directive. The agency also issued brief, periodic bulletins with human resources data in specific fields of science and of application.

Evidently the quality and utility of these early quantitative studies were quickly recognized, since an Executive Order issued by President Eisenhower on March 4, 1954, required, among other matters, that:

The Foundation shall continue to make comprehensive studies and recommendations regarding the Nation’s scientific research effort and its resources for scientific activities, including facilities and scientific personnel, and its foreseeable scientific needs, with particular attention to the extent of the Federal Government’s activities and the resulting effects upon trained scientific personnel. In making such studies, the Foundation shall make full use of existing sources of information and research facilities within the Federal Government.³⁶

One reason why President Eisenhower may have singled out NSF as the most appropriate agency to conduct such studies was the unique partnership among the industrial, academic, and Federal Government sectors reflected in the congressionally mandated composition of the NSB, “so selected as to provide representation of the views of scientific leaders in all areas of the Nation.”³⁷ Congress also recognized the Board’s ability to speak with authority on matters pertaining to the vitality of the U.S. science and engineering enterprise. In 1968, the House Committee on Science and Technology, chaired by Emilio Q. Daddario (D-CT), held a series of oversight hearings resulting in the first major set of amendments to the National Science Foundation Act of 1950. Among other things, these amendments provided for a presidentially appointed deputy director, authorized NSF to support applied research, and explicitly authorized support for research in the social sciences. The Daddario amendments also required that:

The [National Science] Board shall render an annual report to the President, for submission on or before the 31st day of January of each year to the Congress, on the status and health of science and its various disciplines. Such report shall include an assessment of such matters as national scientific resources and trained manpower, progress in selected areas of basic scientific research, and an indication of those aspects

of such progress which might be applied to the needs of American society. The report may include such recommendations as the Board may deem timely and appropriate.³⁸

Finally, Congress officially concurred with, and made more explicit, the Executive Order issued by President Eisenhower in 1954 by authorizing and directing NSF:

(6) to provide a central clearinghouse for the collection, interpretation, and analysis of data on scientific and engineering resources and to provide a source of information for policy formulation by other agencies of the Federal Government.

(7) to initiate and maintain a program for the determination of the total amount of money for scientific and engineering research, including money allocated for the construction of the facilities wherein such research is conducted, received by each educational institution and appropriate nonprofit organization in the United States, by grant, contract, or other arrangement from agencies of the Federal Government, and to report annually thereon to the President and the Congress.³⁹

Science Indicators – 1972, et seq.

Roger W. Heyns, a psychologist who served as a member of the NSB from 1967 to 1976 and who became president of the American Council on Education in 1972, suggested that, for its mandated 1973 annual submission to the President and Congress, the Board might consider preparing a report analogous to periodic reports that assessed various economic and social trends in terms of quantitative data series known as social indicators. Preparation of such a report could draw on the proven capabilities of NSF staff in gathering and analyzing quantitative data on U.S.—and international—science and engineering enterprise. The NSB accepted Heyns’ suggestion, naming its fifth report to Congress, *Science Indicators – 1972* (NSB 1973). The positive reception accorded to this first *Indicators* volume encouraged the Board to continue to issue these reports on a biennial basis.⁴⁰

In May 19, 1976, testimony before the House of Representatives’ Subcommittee on Domestic and International Scientific Planning, Heyns highlighted some of the main purposes and functions of the *Indicators* reports:

- ♦ to detect and monitor significant developments and trends in the scientific enterprise, including international comparisons;

³⁸National Science Foundation–Function–Administration, Public Law 90-407, enacted July 18, 1968.

³⁹Public Law 90-407, Section 3(a)(6) and (7).

⁴⁰According to H. Guyford Stever, who was NSF director from 1972 to 1976, one of the first significant policy impacts of *Science Indicators – 1976* occurred as a result of a meeting that he and representatives of NSB had with then-Vice President Gerald R. Ford in the spring of 1974. Vice President Ford was particularly interested in the charts showing that other countries were increasing their R&D/GDP investments whereas the comparable ratio for the United States was decreasing. Soon after becoming President in August 1974, Ford set about increasing Federal R&D investments.

³⁴Public Law 81-507, Section 3(a).

³⁵See footnote 33.

³⁶Executive Order 10521, “Concerning Government Scientific Research,” Section 2. Reissued and amended on March 13, 1959.

³⁷Public Law 81-507, Section 4(a).

- ♦ to evaluate their implications for the present and future health of science;
- ♦ to provide continuing and comprehensive appraisal of U.S. science;
- ♦ to establish a new mechanism for guiding the Nation's science policy;
- ♦ to encourage quantification of the common dimensions of science policy, leading to improvements in research and development policy setting within Federal agencies and other organizations; and
- ♦ to stimulate social scientists' interest in the methodology of science indicators as well as their interest in this important area of public policy (NSB 1993b, xi).

Heyns clearly regarded the periodic preparation of the *Indicators* reports in terms of partnerships involving producers, users, and science policy scholars. The Board has called on all these groups over the years as it seeks to expand and refine these reports in order to reflect both the principal issues enduring in and changing science policy and the best scholarly thinking on quantification of these issues.⁴¹

In 1982, Congress officially recognized the unique significance of the *Indicators* reports by requiring that, instead of more broadly defined annual reports on the status and health of science required by the 1968 amendment to the National Science Foundation Act, "The Board shall render to the President, for submission to the Congress no later than January 15 of each even numbered year, a report on indicators of the state of science and engineering in the United States."⁴²

This same legislation also encouraged submission of other reports on important science- and engineering-related issues, stating that "The Board shall render to the President for submission to the Congress reports on specific, individual policy matters related to science and engineering and education in science and engineering, as the Board, the President or the Congress determines the need for such reports."

Beginning with the 1987 edition, and consistent both with this legislation and the changing character of the U.S. research enterprise, the titles of these mandated biennial reports became *Science and Engineering Indicators*.

Presidential Statements

U.S. presidents from Franklin D. Roosevelt through William J. Clinton have demonstrated their recognition of the importance of science and engineering in a number of ways: through, for example, annual budget submissions to Congress, organizational initiatives designed to improve the effectiveness of the Federal Government's research and policy-making systems, and programmatic initiatives using science and

engineering to advance critical items on their broad policy agenda. (See sidebar, "Major Presidential Science Policy Initiatives.") However, few presidents have given public addresses focused primarily on their science policies. The first notable exception was a speech delivered by President Truman in September 1948 during the first time of transition. Almost exactly 50 years later, in February 1998 during the current time of transition, President Clinton also delivered a public science policy address.⁴³ A comparison between these two speeches indicates both the endurance of several key science policy themes over the past half-century and the significant changes in emphasis that have occurred during that time.

Harry S Truman, 1948

President Truman delivered his address at the opening session of the Centennial Meeting of AAAS in Washington, D.C. (Truman 1948). A report of his speech was featured the next day on a front-page article in *The New York Times*. Truman used the occasion to propose a national science policy whose five principal elements were drawn directly from the report Steelman published a year earlier.

First, the President called for a doubling of total national R&D expenditures over the next 10 years so that, by 1958, those expenditures would exceed \$2 billion and would be equal to 1 percent of GDP, or what he referred to as national income. The occasion of President Truman's AAAS address marked the first instance in which a leading political figure proposed that U.S. national R&D investments should be gauged in terms of GDP. As it happened, by 1958, national R&D investments had far exceeded the challenge that President Truman had laid down 10 years earlier. According to official estimates, in 1948, national R&D expenditures were slightly less than 0.5 percent of GDP; by 1958, that ratio was estimated to have been 2.36 percent. Changes in the Department of Defense's accounting system during the 1948–58 period make it difficult to compare R&D expenditures over that period.⁴⁴ But it is reasonable to assume that the R&D/GDP ratio, calculated according to the prevailing accounting practices of 1948, would have been closer to 2 than to 1 percent by 1958.

When President Truman spoke to AAAS, however, he could not have foreseen two of the principal reasons for the spectacular increases in national R&D expenditures that were to occur during the next decade: first, a rapid growth in defense R&D following the invasion of South Korea in June 1950; second, substantial increases for basic research and space-related R&D following the launching of Sputnik I by the Soviet Union in

⁴¹Papers presented at a symposium organized to critique the first, 1972 report were published in Elkana et al. (1978).

⁴²Congressional Reports Act, Public Law 97-375, Section 214, enacted December 21, 1982.

⁴³President Dwight D. Eisenhower announced the appointment of a full-time science advisor in a national radio address on November 7, 1957. President John F. Kennedy made a major science policy address at the Centennial celebration of NAS on October 23, 1963 (NAS 1963). President James E. Carter spoke at NAS on April 23, 1979, on the occasion of its annual meeting (*Weekly Compilation of Presidential Documents* 1979).

⁴⁴Beginning in FY 1953, the Department of Defense began to include salaries and related expenses of personnel engaged in R&D in its estimates of R&D expenditures, resulting in an increase of approximately \$1 billion in its estimated R&D expenditures between FY 1952 and FY 1953 (NSF 1968, 221, note c).

Major Presidential Science Policy Initiatives

♦ **Franklin D. Roosevelt (1933–45)** requested the first comprehensive survey and analysis of Federal science and technology resources and programs, entitled *Research—A National Resource* (1938). In 1941, he created the Office of Scientific Research and Development to mobilize the Nation's science and engineering resources for World War II, and in November 1944 asked for recommendations on how the lessons learned in mobilizing science for war could serve the Nation in peacetime.

♦ **Harry S. Truman (1945–53)** worked with Congress to shape legislation creating three major agencies: the Atomic Energy Commission (1946), the Office of Naval Research (1946), and the National Science Foundation (1950). Truman also established the Science Advisory Committee to the White House Office of Defense Mobilization, the first presidential advisory system.

♦ **Dwight D. Eisenhower (1953–61)** established the President's Science Advisory Committee and appointed a full-time science advisor (1957). He oversaw the launching of the first U.S. satellites and proposed legislation to create the National Aeronautics and Space Administration (July 29, 1958). Eisenhower also worked with Congress to craft legislation—The National Defense Education Act (September 2, 1958)—which significantly increased U.S. Government support for science and engineering education at all levels.

♦ **John F. Kennedy (1961–63)** set the goal of sending a man to the moon by the end of the decade. He established the Office of Science and Technology within the Executive Office of the President in June 1962. He also proposed and oversaw implementation of a presidential-level bilateral science and technology agreement with Japan, the first such bilateral agreement entered into by the United States. Kennedy delivered a major science policy address at the National Academy of Sciences on October 23, 1963, as part of its 100th anniversary celebration.

♦ **Lyndon B. Johnson (1963–69)** emphasized science in service to society by making use of social science data as the basis for his War on Poverty and other components of his Great Society program. In inaugurating Medicare in June 1966, he noted that, as President, he had an obligation to show an interest in how the results of biomedical research are applied. Johnson also maintained U.S. leadership in space.

♦ **Richard M. Nixon (1969–74)** presided over the creation of high-level bodies charged with providing advice on science- and technology-related issues, including the Council on Environmental Quality within the Executive Office of the President (March 1970), the National Advisory Committee on Oceans and Atmosphere (August 1971), and the White House Energy Policy Office (June 1973). His War on Cancer initiative led to considerable

increases in Federal funding for biomedical research. Nixon also realized a goal of a predecessor when Neil Armstrong walked on the moon in July 1969.

♦ **Gerald R. Ford (1974–77)** agreed with Congress that the presidential advisory system, abolished in 1973, should be reestablished, leading to a May 1976 Act creating the Office of Science and Technology Policy. His annual budget requests included increases in Federal expenditures for nondefense R&D, which had been declining in constant dollar terms since 1968.

♦ **James E. Carter (1977–81)** initiated Federal research programs aimed at developing renewable energy sources, including solar energy and fusion, and established programs to assist industry to demonstrate the feasibility of extracting oil from coal and oil shale. He signed the first bilateral science and technology agreement with the People's Republic of China in 1979.

♦ **Ronald W. Reagan (1981–89)** substantially increased defense R&D expenditures, particularly for his Strategic Defense Initiative, commonly called "Star Wars." He established modest programs within the National Bureau of Standards (now the National Institute for Standards and Technology) to provide research support to industry. Reagan also negotiated a significant expansion in the U.S.–Japan bilateral science and technology agreement, which included Japanese support for U.S. researchers to work in Japan.

♦ **George W. Bush (1989–93)** oversaw the development of the Federal Government's first technology policy, which was intended to augment and extend the established bipartisan consensus on science policy. He increased the size and scope of the National Institute for Standards and Technology's industrial research support programs. With Bush's encouragement, D. Allan Bromley, The Assistant for Science and Technology, emphasized strengthened international scientific interactions, initiating a biannual series of off-the-record meetings with his G-7 counterparts (known as the Carnegie Group meetings) and taking the lead in establishing the Megascience Forum within the Organisation for Economic Co-operation and Development.

♦ **William J. Clinton (1993–2001)** established links between science and technology policy and economic policy with his 1993 policy statement entitled *Technology: The Engine of Economic Growth* (Clinton and Gore 1993) and reaffirmed his commitment to university research and to science and mathematics education by endorsing them in *Science in the National Interest* (Clinton and Gore 1994). Clinton has been a strong advocate of improvements in science education and has expanded Federal support for information technologies substantially through long-term, coordinated interagency initiatives.

October 1957. Federal expenditures increased from \$625 million in 1948 to \$6.8 billion in 1958 (\$5.4 billion in 1948 constant dollars). But Federal expenditures alone did not account for all the increase that occurred during the decade after President Truman's speech. During that same decade, industrial R&D investments rose from an estimated \$450 million to approximately \$3.7 billion in 1958, almost \$3.0 billion in 1948 constant dollars (NSF 1998, 82–93, table B-6).

The *second* element of President Truman's proposed science policy was to place greater emphasis on basic research and medical research. Today, there exists a strong bipartisan consensus that both categories of research need to be adequately supported, even though they are rarely linked as explicitly as in President Truman's AAAS address.

The *third* element of President Truman's proposed science policy—that a National Science Foundation should be established—was, of course, accomplished 21 months later when, on May 10, 1950, he signed the National Science Foundation Act of 1950 into law.

The *fourth* element—that more aid should be granted to universities, for both student scholarships and research facilities—indicated recognition by the administration of the importance of universities to the national research enterprise. Concerns about the World War II human resources deficit discussed in both *Science—The Endless Frontier* and *Science and Public Policy* no doubt underlay President Truman's call for more scholarships. Today, concerns about human resources for science and engineering focus on the composition and distribution of highly trained personnel across disciplines and sectors, while the need to provide adequate facilities for university research remains a perennial issue.

As the *fifth* and final element of his proposed science policy, President Truman stressed the need for better coordination of the work of the Federal research agencies, reflecting the desire of BoB for assistance in maintaining better oversight of the burgeoning Federal R&D enterprise. That concern began to be addressed in April 1951 when President Truman established the SAC/ODM, a body that enjoyed some access to the President and that, in November 1957, was elevated into the PSAC by President Eisenhower.

Having enumerated these elements of his proposed science policy, the President devoted the remainder of his speech to some of the major national needs that U.S. science was being called upon to address, as well as the support that science required in order to address those needs. In 1948, Cold War tensions were rapidly escalating. Not surprisingly, then, the President focused sharply on the obligations of U.S. science to continue to support national security objectives. Significantly, he singled out what he called “pure—or fundamental—research” as an area of the highest importance to the country's long-term national defense requirements.

The President suggested that the Federal Government had two obligations in connection with the U.S. research system: first, to see that the system received adequate funds and facilities; second, to ensure that scientists were provided with

working environments where research progress was possible. Regarding the second of these obligations, he stressed that, “pure research is arduous, demanding, and difficult. It requires intense concentration, possible only when all the faculties of the scientist are brought to bear on a problem, with no disturbances or distractions.” He went on to urge that, to the greatest extent possible, the pursuit of research should be insulated from day-to-day political concerns.

Near the conclusion of his address, President Truman spoke about the need for greater public awareness of the importance of research to the Nation:

The knowledge that we have now is but a fraction of the knowledge we must get, whether for peaceful use or for national defense. We must depend on intensive research to acquire the further knowledge we need ... These are truths that every scientist knows. They are truths that the American people need to understand (Truman 1948, 14).

New knowledge requirements, he emphasized, must encompass all disciplines:

The physical sciences offer us tangible goods; the biological sciences, tangible cures. The social sciences offer us better ways of organizing our lives. I have high hopes, as our knowledge in these fields increases, that the social sciences will enable us to escape from those habits and thoughts which have resulted in so much strife and tragedy (Truman 1948, 15).

“Now and in the years ahead,” he concluded, “we need, more than anything else does, the honest and uncompromising common sense of science. When more of the peoples of the world have learned the ways of thought of the scientist, we shall have better reason to expect lasting peace and a fuller life for all.”

William J. Clinton, 1998

On February 13, 1998, during the current time of transition, President Clinton addressed AAAS at its 150th anniversary meeting in Philadelphia (Clinton 1998). As might have been expected, President Clinton made explicit reference to his predecessor's speech as a means for highlighting the revolutionary changes that had occurred as a result of advances in science and engineering during the intervening half-century. That two of his references were to fields that did not even exist in President Truman's day—namely, space science and information technology—provides one measure of the scope of those changes.

President Clinton's speech touched on many of the issues that President Truman had raised 50 years earlier, although with strikingly different emphases. President Truman's first point was that total national R&D investments should be doubled, reflecting the *Science and Public Policy's* contention that the overall level of those investments was inadequate to the broad needs of the Nation. By contrast, President Clinton was able to remind his audience that the FY 1999 budget proposal that he had recently submitted to Congress included substantial increases for most of the principal Federal research agencies.⁴⁵

⁴⁵Budget of the United States Government for Fiscal Year 1999, p. 93–104.

President Truman had linked basic research with medical research in urging that greater emphasis be given to both. President Clinton spoke more broadly about an expanded commitment to discovery. In noting advances that had occurred in health research, he reminded his audience that these advances had depended upon progress in a wide range of science and engineering fields.

Both presidents spoke about the conditions required for the conduct of high quality research. But where President Truman focused on insulating research from short-term political issues, President Clinton stressed the need for a long-term, stable funding environment.

Perhaps the most telling contrast between the two speeches was with the specific emphases placed on the national objectives that research should serve. President Truman spoke at length about science, engineering, and national security, which was appropriate in a year in which Cold War tensions were markedly increasing. However, the national security theme was entirely absent from President Clinton's speech. Rather, his emphasis was on the economy, the environment, and quality of life. President Clinton also spoke about social responsibility, noting that "it is incumbent upon both scientists and public servants to ensure that science serves humanity always, and never the other way around." As an example, he referred to ethical problems associated with advances in biotechnology, a reference that President Truman could not possibly have made, since the structure of the DNA molecule, a prerequisite for modern, molecular-based biotechnology, was not to be discovered until 1953.

A good deal of President Truman's speech had to do with the obligations of the Federal Government toward science; in contrast, President Clinton emphasized the need for strengthened partnerships between science and other national sectors.

Both presidents touched on the public understanding of science: President Truman stressing the need for Americans to understand the special needs of research; President Clinton, the need to increase public awareness of the promise of science for the future.

Both Presidents Truman and Clinton concluded their remarks by looking toward futures that appeared very different in 1948 and 1998. President Truman's optimism was guarded, reflecting the still fresh memories of World War II and the uncertainties inherent in the deepening Cold War. In contrast, President Clinton's concluding remarks, which linked advances in knowledge with fundamental American values, were buoyant:

I believe in what you do. And I believe in the people who do it. Most important, I believe in the promise of America, in the idea that we must always marry our newest advances and knowledge with our oldest values, and that when we do that, it's worked pretty well. That is what we must bring to the new century (Clinton 1998, 10).

Current Visions/Key Policy Documents

Science in the National Interest (1994)

The concept of a National Science Foundation began to take shape in 1944, near the end of a period in which national defense had dominated the Nation's agenda. Only a handful of visionaries in science and government understood that a well-articulated policy would be required in order for the Nation to derive optimum peacetime benefits from science and engineering.

As the 1990s opened, the United States faced the novel challenge of redefining its goals and priorities in the post-Cold War era. By then, the importance of science and engineering to the United States had been firmly established. Indeed, they had assumed a significance that the visionaries of the 1940s probably could not have anticipated. Implementation of the recommendations of *Science—The Endless Frontier* and *Science and Public Policy*, which their authors had assumed would occur in a time of peace, actually took place during a period when national defense considerations once again dominated the national agenda. Thus, with the Cold War over, it was useful to rearticulate the importance of science and engineering to the Nation and redefine their roles in an era in which social and economic concerns were destined to increase in importance relative to national security concerns.

The organization of science and technology within the Federal Government also evolved during the Cold War era in response to changing political, economic, and social circumstances. In May 1976, the U.S. Congress, with the encouragement of President Gerald R. Ford, created the Office of Science and Technology Policy (OSTP) within the Executive Office of the President, in effect reconstituting the Office of Science and Technology (OST), which had been created by President John F. Kennedy in 1962 and abolished by President Richard M. Nixon in 1973. The National Science and Technology Policy, Organization and Priorities Act of 1976 also provided for an external presidential committee analogous to PSAC, which President Nixon abolished at the time he abolished OST. This provision was finally implemented in 1989 when D. Allan Bromley, the President's Assistant for Science and Technology, convinced President George Bush to establish the President's Council of Advisors on Science and Technology. In a coordinated action, Bromley reinvigorated the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), a body consisting of the heads of all U.S. Government agencies with significant science and technology responsibilities. In 1993, President Clinton expanded the membership of FCCSET to include the heads of appropriate agencies within the Executive Office of the President, renaming it the National Science and Technology Council (NSTC).

In 1994, 50 years after Senator Harley Kilgore (D-WV) introduced his first bill to create a National Science Foundation and President Roosevelt requested advice from Vannevar Bush on the organization of science in the post-World War II

era, the OSTP, in cooperation with the leading Federal science and technology agencies, convened a Forum on Science in the National Interest at NAS. Approximately 200 individuals from academia, industry, professional societies, and government participated in this event, suggesting the current breadth and reach of the U.S. science and engineering enterprise. *Science in the National Interest*, published in August 1994, summarized its results (Clinton and Gore 1994).

The organization of the Forum on Science in the National Interest, and the auspices under which it was convened, exemplified some of the important changes that had occurred in the status of science during the previous 50 years—in part as a result of recommendations made during the first period of transition. *Science—The Endless Frontier* was based upon the private deliberations of four *ad hoc* committees of prominent scientists convened to respond to a November 1944 letter from President Roosevelt. *Science and Public Policy* was prepared by a handful of mid-level staff within the Executive Office of the President, who consulted with colleagues in other Federal agencies and augmented their work by means of commissioned reports from nongovernment organizations. One of its recommendations was to establish a mechanism to bring important science policy issues to the attention of the highest levels of government.

OSTP, which convened the January 31–February 1, 1994, forum, was created to ensure that important science policy issues would, in fact, receive attention at the highest levels of the Federal Government. The fact that that agency even existed and was able to bring together approximately 200 individuals broadly representative of the Nation's science and engineering interests to articulate a vision for the future rather than relying on a group of select committees or staff within the Federal agencies suggests the changed social context in which science policy is viewed since the first time of transition.

Although the key documents of the 1940s argued persuasively that investments in science would yield significant benefits, they offered no specific, detailed examples. In contrast, *Science in the National Interest* included a variety of one-page, illustrated descriptions of benefits derived from those investments.

The most striking example of an advance that has occurred as a result of research investments was the simple, almost taken-for-granted fact that the entire text of *Science in the National Interest* was made available by way of the Internet, a development that even visionaries who predicted the bright future of information and communications technologies could not have dreamed of 50 years ago.

Science in the National Interest noted explicitly that its preparation did, in fact, occur during a time of transition. After paying its respects to the visionaries of the late 1940s, its second chapter, entitled “A Time of Transition,” went on to articulate the new context in which national science policy must be formulated:

The end of the Cold War has transformed international relationships and security needs. Highly competitive economies have emerged in Europe and Asia, putting new stresses on

our private sector and on employment. The ongoing information revolution both enables and demands new ways of doing business. Our population diversity has increased, yielding new opportunities to build on a traditional American strength. Health and environmental responsibility present increasingly complex challenges, and the literacy standards for a productive and fulfilling role in twenty-first century society are expanding beyond the traditional “three R’s” into science and technology (Clinton and Gore 1994, 3).

The report then suggested a framework for national science policy in terms of five goals regarded as essential to permit the U.S. scientific and engineering enterprise to address essential national objectives:

1. Maintain leadership across the frontiers of scientific knowledge.
2. Enhance connections between fundamental research and national goals.
3. Stimulate partnerships that promote investments in fundamental science and engineering and effective use of physical, human and financial resources.
4. Produce the finest scientists and engineers for the twenty-first century.
5. Raise scientific and technological literacy of all Americans (Clinton and Gore 1994, 7).

While stressing the desirability of reexamining and reshaping U.S. science policy, *Science in the National Interest* also emphasized that the core values that have enabled the Nation to achieve so much should be kept clearly in view. A strong commitment to investigator-initiated research and merit review based on evaluation by scientific peers should be regarded as foremost among those core values.

Unlocking Our Future (1998)

In October 1945, the U.S. Senate convened hearings on proposed legislation to create a National Science Foundation that involved a large number of witnesses from different sectors of the science and engineering enterprise, from education associations, BoB, and several old-line executive branch scientific bureaus. These and other, subsequent congressional hearings on issues such as control of nuclear energy or research in the military departments were instrumental in focusing widespread public attention on the importance of science and engineering in the postwar era. They also initiated a tradition of sustained congressional interest and attention to U.S. science policy. (See sidebar, “Congressional Science Policy Hearings and Studies.”)

Following that tradition, on February 17, 1997, the Speaker of the House of Representatives acknowledged the need to reexamine the assumptions underlying U.S. science policy by requesting that the House Science Committee undertake a special study. Accordingly, Representative Vernon Ehlers (R-MI), a Ph.D. physicist and former college professor, was asked to lead a Committee study of “the current state of the Nation’s science and technology policies” and to outline “a framework

for an updated national science policy that can serve as a policy guide to the Committee, Congress, and the Nation” (U.S. House of Representatives Science Committee 1998, 6). The full Science Committee held seven hearings in order to obtain inputs for the study. In addition, Committee members and staff met with individuals and groups interested in reexamining U.S. science policy. Finally, the Committee took advantage of advances in information and communications technology by establishing a Web site to elicit comments and suggestions from the public, and the report itself was first made available to the public with the use of the Internet. The Committee successfully completed its work with the release of the report, entitled *Unlocking Our Future: Toward a New National Science Policy*—which was first made available to the public by way of the Internet—on September 24, 1998.

The Ehlers study was guided by a vision statement, which also provided the foundation for its report, namely, “The United States of America must maintain and improve its preeminent position in science and technology in order to advance human understanding of the universe and all it contains, and to improve the lives, health, and freedom of all peoples” (U.S. House of Representatives Science Committee 1998, 7).

Unlocking Our Future noted that three basic components of the scientific enterprise needed to be strengthened to ensure that this vision would be realized:

First, ...we must ensure that the well of scientific discovery does not run dry, by facilitating and encouraging advances in fundamental research;

Second, we must see that ... discoveries from this well must be drawn continually and applied to the development of new products or processes, to solutions for societal or environmental challenges, or simply used to establish the foundation for further discoveries;

Finally, we must strengthen both the education we depend upon to produce the diverse array of people who draw from and replenish the well of discovery, as well as the lines of communication between scientists and engineers and the American people (U.S. House of Representatives Science Committee 1998, 12).

The report went on to discuss these components in considerable detail in terms of themes and issues that, along with those articulated in *Science in the National Interest*, provide a useful counterpoint to the themes and issues set forth in the key documents of the first time of transition.

Themes and Issues

Science in Service to Society

Because the objective of both *Science in the National Interest* and *Unlocking Our Future* was to reexamine science policy in a changing economic, political, and social context, both laid considerable emphasis on science in service to society. *Science in the National Interest* asserted that “We must reexamine and reshape our science policy both to sustain America’s preeminence in science and to facilitate the role of science in the broader national interest” (Clinton and Gore 1994, 3).

Both reports emphasized the importance of research to health, economic prosperity, national security, environmental responsibility, and improved quality of life, as well as its contribution to the general culture. *Unlocking Our Future* also stressed the importance of science and engineering results to decisionmaking:

We believe this role for science will take on increasing importance, particularly as we face difficult decisions related to the environment. Accomplishing this goal will require, among other things, the development of research agendas aimed at analyzing and resolving contentious issues, and will demand closer coordination among scientists, engineers, and policymakers (U.S. House of Representatives Science Committee 1998, 5).

Research Investments

Both reports acknowledged the indispensable role that Federal research investments play in maintaining the preeminence of the U.S. science and engineering enterprise and tacitly assumed that a broad bipartisan consensus to maintain that support would persist. According to *Science in the National Interest*,

To fulfill our responsibility to future generations by ensuring that our children can compete in the global economy, we must invest in the scientific enterprise at a rate commensurate with its growing importance to society. That means we must provide physical infrastructure that facilitates world class research, including access to cutting-edge scientific instrumentation and to world-class information and communication systems (Clinton and Gore 1994, 1).

Unlocking Our Future emphasized that:

Science—including understanding-driven research, targeted basic research, and mission-directed research—must be given the opportunity to thrive, as it is the precursor to new and better understanding, products and processes. The Federal investment in science has yielded stunning payoffs. It has spawned not only new products, but also entire industries (U.S. House of Representatives Science Committee 1998, 4).

Character of the Research System

Both reports agreed that, although adequate Federal support would continue to be essential to the science and engineering enterprise and would almost certainly continue to be forthcoming, its level would continue to be constrained. Therefore, it would be necessary to establish priorities for Federal support, taking into account the current and future character of the research system and its ability to contribute to societal goals. *Unlocking Our Future* stressed the need to take into account the entire Federal Government science and technology system, including the mission agencies, in determining priorities for Federal investments: “Research within Federal government agencies and departments ranges from purely basic knowledge-driven research, to targeted basic research, applied research and, in some cases, even product development” (U.S. House of Representatives Science Committee 1998, 16).

Congressional Science Policy Hearings and Studies

♦ **Hearings on National Science Foundation legislation (October–November 1945).** Joint hearings on two separate bills to create a National Science Foundation were held by the Senate Committee on Military Affairs starting on October 8, 1945, and extending to November 2 (England 1983). (See “Congressional Initiatives.”) These hearings, which involved approximately 100 witnesses, provided the first occasion for a wide-ranging exploration of the status and future potential of science–government relations, including Federal support for research and education, and government organization for science. Representatives of *ad hoc* groups of nuclear physicists who were opposed to continued control of nuclear energy by the War Department used these hearings as the first opportunity to air their views in Congress, leading eventually to a decision of Senator Brien McMahon (D-CT) to introduce legislation (through another committee) that led to the creation of the Atomic Energy Commission on August 1, 1946. These hearings also resulted in a compromise bill to create a National Science Foundation, which passed the Senate in July 1946 but died when the House of Representatives declined to consider it.

♦ **Hearings on space policy (1957–58).** On November 25, 1957, six weeks after the Soviet Union launched Sputnik I on October 4, the Preparedness Subcommittee of the Senate Armed Services Committee convened hearings on U.S. space activities under the chairmanship of Senate Majority Leader Lyndon B. Johnson (D-TX) (U.S. House of Representatives 1980, 5–27). One immediate outcome was the establishment by the Senate of a Committee on Space Astronautics, chaired by Johnson, on February 6, 1958. The House followed suit on March 5 by establishing a Select Committee on Astronautics and Space Exploration chaired by House Majority Leader John McCormack (D-MA), with Representative Gerald R. Ford (R-MI) one of six minority members. Hearings before the Senate and House Committees resulted in the enactment of legislation to create the National Aeronautics and Space Administration on July 29, 1958. As a result of the impressive achievements of its Select Committee, the House also decided to establish a Standing Committee on Science and Astronautics on January 3, 1959.

♦ **Review of the National Science Foundation (1965–68).** In 1963, George P. Miller (D-CA), Chairman of the House Committee on Science and Astronautics, convinced his colleagues that, because of the increasing size and complexity of the Federal research system, the House should establish a mechanism to permit a more continuous, in-depth oversight of the system than had previously been necessary (U.S. House of Representatives 1980, 127–62). Accordingly, the Subcommittee on Science, Research, and

Development, chaired by Emilio Q. Daddario (D-CT), was created on August 23, 1963. Among the subcommittee’s first actions were to organize a series of periodic special seminars and panels with the objective of providing opportunities for members of Congress to meet and interact with members of the science and engineering communities; to request a detailed study from the Legislative Reference Service of the Library of Congress on the aids and tools available to Congress in the area of science and technology; and to send to the House floor legislation to create a Science Policy Research Division within the Library of Congress, which was enacted in 1964. In December 1965, the subcommittee received from this new unit a report titled *The National Science Foundation—Its Present and Its Future*, which provided the basis for a series of hearings designed to revise, update, and broaden the National Science Foundation Act of 1950. These hearings demonstrated widespread support for the Foundation, but also suggested that the agency had become a sufficiently significant component of the U.S. science and engineering enterprise to play a more active role than had been the case up to that time. Legislation enacted on July 18, 1968, amended the 1950 Act by requiring annual authorization for the agency; elevating its deputy director to the status of a presidential appointee; including the social sciences explicitly among those qualifying for National Science Foundation support; requiring that National Science Foundation analyze rather than simply gather and disseminate data on the condition of the science and engineering enterprise; and requiring that the National Science Board submit an annual report to the Congress through the President. (See “Congressional and Presidential Directives.”)

In November–December 1969, the Subcommittee held a series of hearings that resulted, in 1972, in an Act to create the Office of Technology Assessment. Daddario was subsequently selected as the Office of Technology Assessment’s first director.

♦ **Review of Federal policy and organization for science and technology (1973–76).** The Presidential Science Advisory System, established by President Eisenhower with the creation of the President’s Science Advisory Committee and the appointment of James Killian as his full-time science advisor, and expanded with President Kennedy’s creation of the Office of Science and Technology within the Executive Office of the President, enjoyed broad support in the Congress. After the President’s Science Advisory Council and the Office of Science and Technology were abolished in January 1973, the House Subcommittee on Science, Research, and Development convened hearings, beginning in July of that year, on Federal policy and organization for science and

technology.* Expanded hearings were held before the full parent Committee on Science and Technology in June–July 1975.** A majority of witnesses, including six former presidential science advisors, urged that Congress enact legislation to reestablish some type of presidential science advisory system. Parallel hearings leading to a similar conclusion were also held by the Subcommittee on the National Science Foundation of the Senate Committee on Labor and Public Welfare, chaired by Senator Edward M. Kennedy (D-MA). Gerald R. Ford, who became President following the resignation of Richard M. Nixon on August 8, 1975, was sympathetic to recreating such a system and directed Vice President Nelson A. Rockefeller to negotiate the matter with the Senate and House. These negotiations led to enactment, on May 11, 1976, of legislation creating the Office of Science and Technology Policy within the Executive Office of the President and articulating for the first time the consensus of Congress on the principles and elements of an adequate national science policy.***

◆ **House Science Policy Task Force study (1985–86).**

In 1984, Congressman Don Fuqua (D-FL), Chairman of the House Science and Technology Committee, noted that Congress had not organized a broad review of national science policy since the Daddario Subcommittee hearings 20 years earlier. In July of that year, he convinced his colleagues to establish an *ad hoc* Science Policy Task Force within the Committee, which he also agreed to chair. During 1985 and 1986, the Fuqua task force held hearings on the entire range of science policy issues, including Federal support for research, research facilities in universities and Federal laboratories, science education,

university–industry cooperation, the role of the public in setting the national research agenda, and international scientific cooperation, with an emphasis on cooperation in “big science.” The task force also commissioned several special studies, including a collection of articles entitled *Reader on Expertise and Democratic Decision Making* and *A History of Science Policy in the United States, 1940–85*. The results of the two-year task force study were published in a multivolume set.

◆ **House Science Committee study (1997–98).** In February 1997, the Speaker of the House of Representatives requested that the House Science Committee,**** Chaired by James Sensenbrenner (R-WI), conduct a study to outline “a framework for an updated national science policy that can serve as a policy guide to the Committee, Congress, and the Nation.” (See “Current Visions/Key Policy Documents.”) Hearings and special meetings during the next two years under the guidance of Vernon Ehlers (R-MI) led, on September 24, 1998, to the release of a report entitled *Unlocking Our Future* (U.S. House of Representatives Science Committee 1998). Consisting of 51 pages of text, including four pages of summary recommendations, in addition to a four-page list of sources, the Ehlers report grouped its findings under four major headings: (I) Ensuring the Flow of New Ideas, (II) The Private Sector’s Role in the Scientific Enterprise, (III) Ensuring that Technical Decisions Made by Government Bodies Are Founded in Sound Science, and (IV) Sustaining the Research Enterprise—The Importance of Education. In presentations to several scientific society meetings, Congressman Ehlers expressed the hope that the report would be only a first step in an ongoing process in which Congress would focus more actively on science policy, perhaps reviewing it every five years.

*U.S. Code Congressional and Administrative News, 94th Congress, Second Session, vol. I, pp. 882–903.

**The Committee on Science and Astronautics was renamed the Committee on Science and Technology in January 1975.

***National Science and Technology Policy, Organization, and Priorities Act of 1976. Public Law 94-282, enacted May 11, 1976.

****The House Science and Technology Committee was renamed the House Science Committee in January 1995.

Unlocking Our Future also recognized the indispensable and increasingly important role of private industry both as supporter and performer of research. However, both reports emphasized the centrality of universities to the entire U.S. research enterprise. *Science in the National Interest* asserted that:

A significant fraction of research, particularly fundamental research, is performed at academic institutions. This has multiple benefits. Research and education are linked in an extremely productive way. The intellectual freedom afforded academic researchers and the constant renewal brought by successive generations of inquisitive young minds stimulate the research enterprise (Clinton and Gore 1994, 7).

The increasing importance of multidisciplinary research, particularly as a basis for addressing national goals, was also emphasized by both reports.

Human Resources for Science and Engineering

Both reports assigned a high priority to human resources as an integral element of science policy. *Science in the National Interest* stated that “The challenges of the twenty-first century will place a high premium on sustained excellence in scientific research and education. We approach the future with a strong foundation” (Clinton and Gore 1994, 2). An adequate education for the 21st century requires greater flexibility, particularly at the graduate school level. *Unlocking Our Future* asserted that “While continuing to train scientists and engineers of unsurpassed quality, the higher education process should allow for better preparation of students who plan to seek careers outside of academia by increasing flexibility in graduate training programs” (U.S. House of Representatives Science Committee 1998, 42).

Both reports agreed that science education at all levels, including adequate science education for nonspecialists, was essential to the national interest. According to *Unlocking Our Future*, “Not only must we ensure that we continue to produce world-class scientists and engineers, we must also provide every citizen with an adequate grounding in science and math if we are to give them an opportunity to succeed in the technology-based world of tomorrow—a lifelong learning proposition” (U.S. House of Representatives Science Committee 1998, 5).

Partnerships

Preparation of both reports involved the active participation of individuals and groups with interests in the U.S. science and engineering enterprise. Appropriately, then, both emphasized the importance of partnerships in maintaining the vitality of the enterprise and strengthening its links with society. *Unlocking Our Future* took special note of the fact that:

The science policy described herein outlines not only possible roles for Federal entities such as Congress and the Executive branch, but also implicit responsibilities of other important players in the research enterprise, such as States, universities and industry. We believe such a comprehensive approach is warranted given the highly interconnected relationships among the various players in the science and technology enterprise (U.S. House of Representatives Science Committee 1998, 11).

More broadly,

Each member of society plays an important part in the scientific enterprise. Whether a chemist or a first-grade teacher, an aerospace engineer or machine shop worker, a patent lawyer or medical patient, we all should possess some degree of knowledge about, or familiarity with, science and technology if we are to exercise our individual roles effectively (U.S. House of Representatives Science Committee 1998, 36).

Science in the National Interest noted that:

Science advances the national interest and improves our quality of life only as part of a larger enterprise. Today’s science and technology enterprise is more like an ecosystem than a production line. Fundamental science and technological advances are interdependent, and the steps from fundamental science to the marketplace or to the clinic require healthy institutions and entrepreneurial spirit across society (Clinton and Gore 1994, 8).

Accountability

Because the overall objective of both reports was to examine the changing character of science and engineering in a rapidly changing social, economic, and political context, both laid considerable emphasis on public accountability. *Science in the National Interest* asserted the accountability theme simply and concisely at the outset: “The principal sponsors and beneficiaries of our scientific enterprise are the American people. Their continued support, rooted in the recognition of science as the foundation of a modern knowledge-based technological society, is essential” (Clinton and Gore 1994, 1). However, obtaining and maintaining broad public support, as *Unlocking Our Future* emphasized, requires the active engagement of individuals from several types of institution:

Whether through better communication among scientists, journalists, and the public, increased recognition of the importance of mission-directed research, or methods to ensure that, by setting priorities, we reap ever greater returns on the research investment, strong ties between science and society are paramount. Re-forging those ties with the American people is perhaps the single most important challenge facing science and engineering in the near future (U.S. House of Representatives Science Committee 1998, 5).

International Dimensions

Both reports emphasized that cognizance of the international dimensions of research would be essential in formulating an adequate national science policy for the 21st century. *Unlocking Our Future* recognized that international collaborations are among the many types of partnership that individual scientists and engineers require to work effectively: “Although science is believed by many to be a largely individual endeavor, it is in fact often a collaborative effort. In forging collaborations, scientists often work without concern for international boundaries. Most international scientific collaborations take place on the level of individual scientists or laboratories” (U.S. House of Representatives Science Committee 1998, 21).

Science in the National Interest emphasized the importance of the international dimensions of science both to the

U.S. research enterprise and to U.S. national interests more broadly:

The nature of science is international, and the free flow of people, ideas, and data is essential to the health of our scientific enterprise. Many of the scientific challenges, for example in health, environment, and food, are global in scope and require on-site cooperation in many other countries. In addition to scientific benefits, collaborative scientific and engineering projects bring Nations together thereby contributing to international understanding, good will, and sound decision-making worldwide (Clinton and Gore 1994, 8).

Advances in Science and Engineering

NSF funding of basic research across a broad range of disciplines as well as funding from other government agencies, industry, and academia in the United States and abroad has led to many advances. Science and engineering breakthroughs have contributed to new capabilities in equipment that subsequently have enabled newer discoveries. It is not possible to review them all. The following discussion will be only illustrative in nature and will point to other ongoing efforts to identify and document such advances.

Central to the vision of the first transition period was the desirability of encouraging and facilitating partnerships among the three primary sectors of the U.S. research community: academia, industry, and government. Although the relationships among these sectors have changed considerably since that time, these partnerships have been essential to the major advances in all fields of science and engineering that have taken place during the past 50 years. These advances have led us to a better understanding of ourselves and the world around us. Increased understanding has, in turn, underlain the development of new products and processes, which have changed our everyday lives and the way we live them. Deeper understanding of specific aspects of the natural and human-influenced world has also demonstrated how little we know in many cases and suggested the need for new approaches to address important scientific and engineering problems. This finding has led to increased multidisciplinary research, international and intersectoral cooperation, and the creation of disciplines and whole industries (for example, information technology and biotechnology industries) that did not exist during the first transition period. Such advances have changed our lives, our economy, and our society in important and sometimes profound ways.⁴⁶

The View by *Indicators*

Earlier editions of *Science and Engineering Indicators* reports have discussed important discoveries and advances. For example, the “Advances in Science and Engineering” chapter of *Science and Engineering Indicators – 1980* covered the following areas:

- ♦ Black Holes,
- ♦ Gravity Waves,
- ♦ The Sun,
- ♦ Cognitive Science in Mathematics and Education,
- ♦ Information Flow in Biological Systems,
- ♦ Catalysts and Chemical Engineering, and
- ♦ Communications and Electronics.

The *Science and Engineering Indicators – 1982* “Advances in Science and Engineering” chapter covered the following areas:

- ♦ Prime Numbers: Keys to the Code,
- ♦ The Pursuit of Fundamentality and Unity,
- ♦ The Science of Surfaces,
- ♦ Manmade Baskets for Artificial Enzymes,
- ♦ Opiate Peptides and Receptors,
- ♦ Helping Plants Fight Disease, and
- ♦ Exploring the Ocean Floor.

The *Science and Engineering Indicators – 1985* chapter entitled “Advances in Science and Engineering: The Role of Instrumentation” covered five case studies illustrating the important and synergistic roles that refinements in measuring and computing technologies play in undergirding and linking advances in science and engineering, as well as in developing new fields, processes, and products in academia and industry. The chapter highlighted the following areas:

- ♦ *Spectroscopy*—including a discussion of optical spectroscopy, mass spectroscopy, and nuclear magnetic resonance spectroscopy;
- ♦ *Lasers*—including discussions of applications in chemistry, measurement of fundamental standards, commercial applications, and biomedical applications;
- ♦ *Superconductivity*—including discussions of the fundamental process, the search for superconductors, applications, and ultra-high-field magnets;
- ♦ *Monoclonal Antibodies*—including the discovery of the technology, production of pure biochemical reagents, studies of cell development, potential medical applications, and engineered monoclonal antibodies; and
- ♦ *Advanced Scientific Computing*—assisting scientists and engineers to test ideas on the forces moving the Earth’s plates, track the path an electron takes within the magnetic fields of a neutron star, link a fragment of viral DNA to a human gene, watch plasmas undulating within fusion reactors yet to be built, form and reform digital clouds and monitor the formation of tornadoes, see galaxies born and watch their spiral arms take shape, set the clock at the (almost) very beginning and recreate the universe, begin

⁴⁶See “100 Years of Innovation: A Photographic Journey,” *Business Week*, Summer Special Issue 1999 for a remarkable essay of how science, technology, and innovation have changed our lives.

to think about confirming and denying the root theories of proton and neutron structure in order to test our ideas of the nature of matter, and predict how a spacecraft will glide through the atmosphere of Jupiter.

Some of the cutting-edge problems discussed in these earlier chapters remain current. Others have long since been resolved and are now regarded as commonplace. This illustrates the rapidly changing nature of discoveries in science and engineering as well as the difficulties in predicting what new advances will occur and when.

Contributions from the Past and Toward the Future

The basis for some of the advances of the past 50 years occurred during the first transition period. For example, the transistor was invented in 1947, ultimately leading to the invention of microchips in the 1960s. The Electronic Numerical Integrator and Computer, developed by University of Pennsylvania engineers, first became operational in 1948 and was the progenitor of several generations of computers, including the personal computer, first introduced in the 1970s. Information technologies resulted from the fusion of computer and communications technologies. Through information technologies, advances in materials science and physics have led, in turn, to new industries (see NRC 1999 and Huttner 1999), streamlined processes in traditional industries, and expanded scientific capabilities. (See chapter 9 for a discussion of the significance of information technologies.)

Scientists and engineers from all over the globe have joined together to explore space and our universe. Based on accomplishments over time from many countries, the United States was able to send a man to the moon and back in 1969 and a tiny Sojourner rover to Mars in 1997; both captured our imaginations and enhanced our understanding of our universe. Construction of an international space station is now under way with men and women contributing to its development and its associated missions.

The bases for many of the significant advances that have occurred since the late 1940s have been consistent with the importance of developing partnerships as well as the importance of encouraging individual researchers to pursue new and innovative ideas. In the area of medicine, the polio vaccine was developed in the 1950s by physician Jonas Salk, and microbiologist Albert Sabin later developed an oral vaccine. The first heart transplant was performed in 1967. Today many organs are being transplanted or replaced with artificial parts or organs, and researchers are making use of fundamental knowledge to investigate the role of genetics in preventative treatment for some diseases.

The double helical structure of the DNA molecule was discovered in the 1950s, and recombinant DNA techniques (or gene splicing) occurred in the early 1970s, leading to many additional advances. Researchers around the world are striving to complete the human genome project. Advances in a variety of subfields of the biosciences have resulted in vast

amounts of new data, leading to the problem of how to store, interpret, and make these data available to researchers in other subfields. Researchers in computer sciences and biological sciences have addressed this problem by creating the entirely new field of biological informatics, which applies advances in information technology to make possible further understanding of biological systems.

In plant biology, researchers currently apply genetic engineering to develop crops resistant to disease and insects. It is now known that all flowering plants derive from a common ancestry and share a common set of biochemical pathways. This knowledge has led plant biologists to direct their coordinated research efforts toward developing a complete understanding of a small, relatively simple flowering plant, *Arabidopsis*, that serves as a model organism. Scientists around the globe, in a multiagency, multinational project, are mapping and identifying the function and location of all the genes in *Arabidopsis*. New fundamental discoveries from this initiative have already led to significant improvements in several crop plants and may possibly result in totally new crops in the future. The *Arabidopsis* project is also providing information that can be used to study genes from a variety of more complex organisms, ranging from corn and wheat to mice and humans.

Breakthroughs are not without controversy. The cloning of Dolly the sheep, the first mammal to be cloned from an adult cell, has been a triumph and a concern. It is an example of the importance of dialogue with the public and better understanding of societal concerns. Findings in Chapter 8 on public attitudes and understanding of science and technology show that the public greatly appreciates scientific discoveries, although they do not always fully understand them. Also a large majority believe that in general the benefits of scientific research outweigh harmful results. Nonetheless, when asked about genetic engineering, the U.S. public's answers are more evenly divided.

Over the past half-century, discoveries associated with NSF funding⁴⁷ include materials science discoveries by engineers, chemists, physicists, biologists, metallurgists, computer scientists, and other researchers. These advances have led to increased data storage capacity of computer systems, advances in semiconductor lasers, improvements in compact disc players and laser printers, new medical applications, and major breakthroughs in synthetic polymers which are found today in products from clothing to automobiles.

Because of the complex nature of both research itself and its links to possible useful products and processes, there is often a delay between the dissemination of fundamental knowledge and its eventual outcome or effect on products or processes. Therefore it is not always easy to trace back to the precise origins of all discoveries. Nevertheless, a number of studies have accomplished this goal. For example, an early study contracted for by NSF, entitled *Technology in*

⁴⁷See *America's Investment in the Future*, an NSF publication in press, for an engaging and broad-ranging discussion of important discoveries made by researchers funded by NSF.

Retrospect and Critical Events in Science (Illinois Institute of Technology 1968; commonly known as the “Traces” study) chronicled and traced the development of important innovations such as magnetic ferrites, videotape recorders, the oral contraceptive pill, the electron microscope, and matrix isolation, an example of a scientific technique used in certain chemical processing industries. In most cases, the traces emphasized the importance of nonmission research and contributions from all sectors and their interplay. The study pointed out the importance of interaction between science and technology and interdisciplinary communication as well as demonstrated the long-term, sometimes serendipitous, nature of innovation. This social science study was a precursor to many of today’s efforts to trace innovations and conduct accountability studies such as called for under the Government Performance and Review Act (see chapter 2 for more explanation of this Act). Current studies and different approaches also demonstrate the close nature of science and technology to new products and processes (NSB 1998b; Narin, Hamilton, and Olivastro 1997).

A more traditional way of acknowledging important scientific discoveries and breakthroughs is with awards. The most famous scientific award is the Nobel Prize. Appendix table 1-1 lists the various Nobel Prizes since the 1950s and the accomplishments that they celebrate. An examination of the discoveries listed provides a glimpse into the progress in several fields.

Research is increasingly collaborative and interdisciplinary in nature. Findings from one country, discipline, or sector can build on those developed in others, highlighting the importance of alliances and partnerships. Chapters 2 and 6 show how such collaborative activities have increased over the past decade. As one important example of interdisciplinary research, computer scientists, mathematicians, and cognitive scientists have joined forces with scholars in the humanities to conduct research on modeling and visualization techniques to address a variety of problems from modeling the human heart or brain to modeling traffic patterns. Nanotechnology is another important emerging interdisciplinary field that has many potentially valuable applications. International cooperation has also increased considerably during the past 50 years, with many large-scale scientific projects planned and financed internationally from the outset.

With the help of ever more powerful instruments—be it the Hubble telescope or the new Gemini telescopes—astronomers and astrophysicists are increasing understanding of our solar system and even reaching beyond to discover planets outside of our solar system. An important recent example is the Gemini project, to construct and operate a pair of identical, state-of-the-art, 8-meter optical telescopes in the Northern and Southern Hemisphere (at Mauna Kea, Hawaii, and Cerro Pachon, Chile). Project Gemini is an international project involving the United States, the United Kingdom, Canada, Argentina, Australia, Brazil, and Chile. Gemini North has been dedicated and has provided some of the sharpest

infrared images ever obtained by a ground-based telescope. These first high-resolution images from Gemini North reveal the remarkable power of the telescope’s technologies, which minimize distortions that have blurred astronomical images since Galileo first pointed a telescope skyward almost 400 years ago. The clarity of these images is equivalent to resolving the separation between a set of automobile headlights at a distance of 2,000 miles.

Large-scale physics facilities such as Centre Européenne pour la Recherche Nucléaire and its Large Hadron Collider are also investigating the structure of our universe from the atomic to the cosmic scale in a fascinating and different fashion. The work of astronomers and physicists have created new knowledge about the infinite vastness and smallness of our marvelous universe. *Physics in the Twentieth Century* by Curt Supplee (1999) documents many of the important breakthroughs in physics, and the May 1999 issue of *Physics Today* heralds many of the triumphs in astronomy over the past 100 years.

Discoveries in the geosciences and engineering have enabled us to better prepare for and predict disasters such as earthquakes and to mitigate economic and social effects of long-term weather phenomenon such as El Niño. New discoveries related to plate tectonics and discoveries from interdisciplinary polar science research have increased our understanding of our world, its structure, and its atmosphere.

Advances in the social and behavioral sciences cannot be ignored and are key to solving and understanding some of our Nation’s and world’s most complex problems. Better understanding of economics and game theory, risk assessment, and cognitive science have made important contributions to our economy and well-being.

The Importance of Human Resource Development: The NSF Class of 1952

None of these advances could have been accomplished without the hard work of numerous talented scientists and engineers and their students. From the beginning, NSF recognized the importance of educating and training young people in science and engineering fields; improving and linking education and research continue to be a major priority and contribution of NSF. Of the \$3.5 million appropriated by Congress for the new Foundation’s first full fiscal year (from July 1, 1951, through June 30, 1952), NSF expended approximately \$1.07 million for 97 research grants and approximately \$1.53 million to award 535 predoctoral and 38 postdoctoral fellowships.

The new fellows were informed of their awards during the first week of April 1952. Among the predoctoral fellowship recipients, 154 were listed as first-year students, that is, college seniors intending to enroll in graduate school in the fall; 165 were completing their first year as graduate students, and 216 had completed two years or more. Arguably, these 573 fellowships, awarded to aspiring scientists and engineers in 47 states and the District of Columbia, composed the first widely visible indication that NSF was open and ready for business.

The first recipients of NSF fellowships made important contributions from many fields and sectors—both within science and engineering fields and outside of these disciplines. A short historical reprise of what the NSF fellowship meant to these first recipients shows that it helped many to decide to go into science, assisted in bolstering confidence, and made a significant difference in being able to choose their own areas of study. The first fellows included many who would later become prominent, such as Nobel Prize Winners Burton Richter and James Cronin, and Maxine Singer, a co-discoverer of recombinant DNA, now President of the Carnegie Institution of Washington and the 1999 recipient of the NSB's Vannevar Bush award. Also they included many who, although less prominent, have contributed to their fields; to government, industry, and academia; and to their communities.

The following excerpts are from a survey and report of the first fellows by William A. Blanpied, summarized in "The National Science Foundation Class of 1952" (Blanpied 1999). These excerpts give a flavor of the times as well as what the NSF fellowship meant to the careers and lives of these then young people—approximately 100 members of the NSF Class of '52 who responded to a personal letter. This group of scientists and engineers have had professional careers approximately spanning the lifetime of the Foundation, and their recollections of their fellowship years and the impacts of those years on their subsequent professional life provide insights into the personal impacts as well as societal impacts of supporting bright young scientists and engineers. The birth years of these respondents range from 1917 through 1932, the median year being 1929. Many experienced military service in World War II and noted that their undergraduate education had been made possible, at least in part, by benefits received from the GI bill of rights,⁴⁸ which had been enacted in June 1944. U.S. higher education was becoming democratized during their undergraduate years.

Peter von Hippel, among the youngest of the Class of '52, recalled classmates who were "given the GI bill of rights, often considerably older and more mature." Peter von Hippel was then in his last year of a five-year combined bachelor's/master's in science program in biophysics at MIT which he believes was the first undergraduate biophysics program in the country. Von Hippel is now the American Cancer Society Research Professor of Chemistry at the Institute of Molecular Biology at the University of Oregon.

Edward O. Wilson, now Pellegrino University Research Professor at Harvard and then a student in Harvard's Department of Biology, recounted the thrill of getting the news of the fellowship. "The announcements of the first NSF predoctoral fellowships fell like a shower of gold on several of my fellow students in Harvard's Department of Biology on a Friday morning in the spring of 1952. I was a bit let down because I wasn't among them, but then lifted up again when I

received the same good news the following Monday (my letter was late)."

Joseph Hull, a geology major at Columbia, recalled, "I knew that there were political implications when Senator Mike Monroney of my home state, Oklahoma, wrote me a congratulatory letter reminding me that he had voted for the bill. I was also aware that supplying geographical diversity by being from Oklahoma gave me an edge in the selection. No matter. I was exhilarated. Being an NSF Fellow carried a lot of prestige." Hull received his doctorate from Columbia in 1955 and then pursued a career with the petroleum industry.

Richard Lewontin, Professor of Biology at Harvard, had even earlier knowledge of NSF. "When I was a high school senior in 1946," he wrote,

I was in the first wave of Westinghouse Science Talent Search winners. One of the things that the group did when we went to Washington was to testify before a congressional committee that was considering the National Science Foundation legislation. As bright high school students, it was our task to tell a somewhat reluctant congressional committee that the Federal support of science through a National Science Foundation would be a good thing. I do not know if that testimony had any influence, but you may well imagine that I remember the occasion very well.

Josephine Raskind, later Peter von Hippel's wife, was a classmate of Lewontin's at Forest Hills High School and a co-Westinghouse finalist. She recalls meeting President Truman and physicist Lise Meitner, among others, on that 1946 trip to Washington.

At least three other members of the NSF Class of '52 had also been Westinghouse finalists. One was Alan J. Goldman, currently in the Mathematical Sciences Department of the Whiting School of Engineering at The Johns Hopkins University, who wrote that the multiday trip to Washington for the finalists was the first time he had been away from his family even overnight. Another was Andrew Sessler, now Distinguished Senior Scientist at the Lawrence Berkeley laboratory. The third was Barbara Wolff Searle, who reported that she was the "top girl" in that group in 1947. Searle was also among 32 women who received NSF fellowships in 1952. Remarkably, 5 of those 32 were seniors at Swarthmore College. "The men who took the exam were not slouches," Searle recalled, "but whatever the test tested, we (the women) did better at." Two other members of the Swarthmore-5 also responded to the November 1998 letter: Vivienne Nachmias, recently retired as Professor in the Department of Cellular and Developmental Biology at the University of Pennsylvania School of Medicine, and Maxine Singer, President of the Carnegie Institution of Washington. Searle herself recently retired from the staff of the World Bank, where she served for several years as an education specialist.

Joseph Berkowitz, who was working in the nuclear reactor program at Brookhaven National Laboratory when he received the fellowship that allowed him to pursue graduate work in chemistry at Harvard, had graduated from New York University as a member of the Class of 1951. "The opportunity to attend graduate school at Harvard opened entirely new

⁴⁸An Act to Provide Federal Government Aid for the Readjustment in Civilian Life of Returning World War II Veterans. Public Law 78-346, enacted June 22, 1944.

vistas for me,” he recalled. “My fellow students were quite different from the ones I encountered as an engineering student. I discovered the addiction to basic research. I had the opportunity to attend lectures by future Nobel Prize winners. It launched me on a life-long career in basic research, which I didn’t know was possible in my youth. It’s probably no exaggeration to say that the NSF predoctoral fellowship changed the direction of my life.” Berkowitz, who spent much of his career at Argonne National Laboratory, is now an Emeritus Senior Scientist at that facility.

Several respondents also noted that their fellowships allowed them to change their research directions. Burton Richter, Director Emeritus of SLAC and a Nobel Laureate in Physics, recalled that, as a student at MIT, he was working ...

on an experiment [at the National Magnet Laboratory] to determine the hyperfine structure of the radioactive mercury isotopes. My job was to make the radioactive mercury isotopes, which I did by a kind of inverse alchemy turning gold into mercury using the MIT cyclotron. I began to find myself more interested in what was going on at the cyclotron laboratory than in what was going on with my experiment. As my interest grew, I decided that perhaps I should change fields. I went off to spend three months at Brookhaven seeing what particle physics was like. I found I loved it and on return transferred to the synchrotron laboratory and began working in the direction that I have pursued ever since. It may be that I could have done all of this with a normal graduate research assistantship but it would certainly have been more difficult. I would have had to find a professor who was willing to spend his own research money to give a young student an opportunity to try out some different area.

Robert M. Mazo, a senior chemistry major at Harvard in the spring of 1952 and now Professor Emeritus in the Department of Chemistry and Institute of Theoretical Science at the University of Oregon, suggested that there were ...

two primary classes of people affected by the fellowship program. There were those like me, already intellectually committed to a career in science, but uncertain about practical ways and means [of financing their graduate education]. Then there were those, many with great abilities, which were unsure about their career aims. The existence of a fellowship program temporarily freeing them from financial stress tipped the balance in favor of a career in science for many.

“My NSF year,” as Swarthmore graduate Vivianne T. Nachmias recalled,

was primarily a year that allowed me to try things out, to search, to take more graduate studies, and so to narrow my field of interest. I had the fixed idea that the only thing to study was the brain. But how? After my year with NSF support [in the Harvard Department of Chemistry], I went across the river to Harvard Medical School and there in the first year, I encountered cells, in my histology course with Helen Padykula as instructor. I did my first successful project with her (on muscle cells) and from then on I was as interested in cells as in the brain.

Nachmias went on to earn a medical degree from the University of Rochester in 1957 and subsequently pursued a career in biomedical research. She conjectured that another reason for her decision to pursue a medical degree rather than a doc-

torate may have been that “at that time there was only, to my knowledge, one woman professor at Harvard, and she, a very successful astronomer, was from Russia.”⁴⁹ One indeed might conclude that there was not much chance of success along traditional graduate lines. On the other hand, one did see practicing physicians, though admittedly not many. The current scene is one of women succeeding in biology all over the place.”

A few of the first fellows reported that, although they had entered graduate school intending to pursue careers in industry, their fellowship years convinced them to turn to academic careers instead. In contrast, George W. Parshall recalled that:

the academic progress and the financial freedom afforded by the fellowship gave me the liberty to explore a career in industry through summer employment. With the concurrence of my advisor, I accepted an offer from the Chemical Department of the DuPont Company to spend the summer of 1953 at their Experimental Station in Wilmington, Delaware. That summer was an eye-opener! I was assigned to work with a team of chemists who were exploring the chemistry of a newly discovered compound, dicyclopentadienyliron, later dubbed ferrocene.

That experience also convinced Parshall to pursue a research career with DuPont after receiving his doctorate from the University of Illinois in 1954.

Certainly many of the recipients benefited personally, and most continue to be grateful for the opportunity given them almost one-half century ago. Harry R. Powers, Jr., who received his doctorate in plant pathology from North Carolina University in 1953 and has recently retired after his career with the U.S. Forest Service, recalled that, in the spring of 1952,

I was in the second year of my Ph.D. program. However, my family had quite a few medical bills that year, and as was usually the case, we had no medical insurance. I could see no way out except to leave school and get a job. Fortunately, our department head had encouraged all of the graduate students to take the test, a hard 8 hours as I recall [the Graduate Record Examination, the primary basis for the selection of fellows during the first year]. When the telegram came saying that I had received the award, I canceled plans to drop out of school since the fellowship provided more than I had been getting.

Responses from several members of the Class of ’52 expressed gratitude to NSF for having helped them launch their careers in science and engineering, a few regretting that they had not done so years earlier. Daniel Lednicer, who received his doctorate in chemistry from Ohio State University in 1954 and went on to pursue a career as a research chemist at the National Cancer Institute, was among those who decided not to wait—and to go straight to the top at that. “Sometime in the spring of 1954,” as he recalled,

renewal of the NSF fellowship for a third year came through. I was awakened bright and early on the morning following the

⁴⁹Nachmias was probably referring to Ceceilia Helene Payne-Gaposchkin, originally from the United Kingdom and a protege of Harlow Shapley; her husband Serge was a White Russian immigrant who worked at the Harvard College Observatory as an astronomer also.

party to celebrate the event by a reporter from the *Columbus Dispatch*. I must have been less than sharp in answering his questions. That renewal did make me realize that it would be appropriate to thank someone for this generous support of my graduate studies. The man who had proposed NSF and steered the bill through Congress was none other than the immediate past President, Harry S Truman, a man whom I admired even back in 1954. So a letter expressing my appreciation went off to him that summer. A letter in an expensive looking envelope with a Kansas City return address arrived in early October.

Lednicer made available a copy of that letter, whose tone is quintessentially Trumanesque:

October 2, 1954

Dear Mr. Lednicer:

Your good letter of September 21 was very much appreciated.

I always knew that the Science Foundation would do a great amount of good for the country and for the world. It took a terrific fight and three years to get it through the Congress, and some smart fellows who thought they knew more than the President of the United States tried to fix it so it would not work.

It is a great pleasure to hear that it is working and I know it will grow into one of our greatest educational foundations.

Sincerely yours,

/s/ Harry S Truman

One thing that is obvious is that the past 50 years' investments in research and education have been an excellent investment in people, ideas, and tools. It is hoped that the next 50 years will be equally as productive and exciting.

Enduring Themes: Continuity and Change

The 1948 and 1998 speeches delivered by Presidents Truman and Clinton, compared and contrasted in an earlier section, qualify as significant indicators of the science policy priorities of those respective presidents. But presidential addresses are rare and subject to time constraints. As a result, only the most essential of their priorities can be presented in public forums.

A comparison of other documents from the 1940s and the current time of transition reinforce a conclusion reached in comparing the speeches made by President Truman and by President Clinton 50 years later: namely, that whereas there is an enduring quality to the science policy themes articulated a half-century ago, changes have also occurred within those overarching themes. In some cases, issues associated with a particular theme have not changed a great deal. In other cases, the character of the issues are very different, reflecting the largely unpredictable changes that have occurred both as a result of advances in science and engineering, and in the social, political, and economic contexts in which science and engineering activities take place.

Examples of the enduring character of many science policy

themes, along with changes in emphasis, can be discerned by comparing some of the principal themes presented in *Science—The Endless Frontier* and *Science and Public Policy* with those presented in *Science in the National Interest* and *Unlocking Our Future*, in addition to those discussed in greater detail in subsequent chapters of *Science and Engineering Indicators – 2000*.

Support and Performance of R&D

National R&D Expenditures

Science and Public Policy included data on estimated U.S. R&D expenditures for 1947 (Steelman 1947, vol. I, 12, table II). (See text table 1-3.) The approximately \$1.2 billion expended during that year was a record high. Nevertheless, the report argued that a national research program that would be adequate to address the Nation's needs would require that those expenditures double by 1957 so that they would then constitute 1 percent of national income (that is, GDP).

Today, total national R&D expenditures for 1998 were estimated at \$220.6 billion, or 2.61 percent of GDP.⁵⁰ (See chapter 2.)

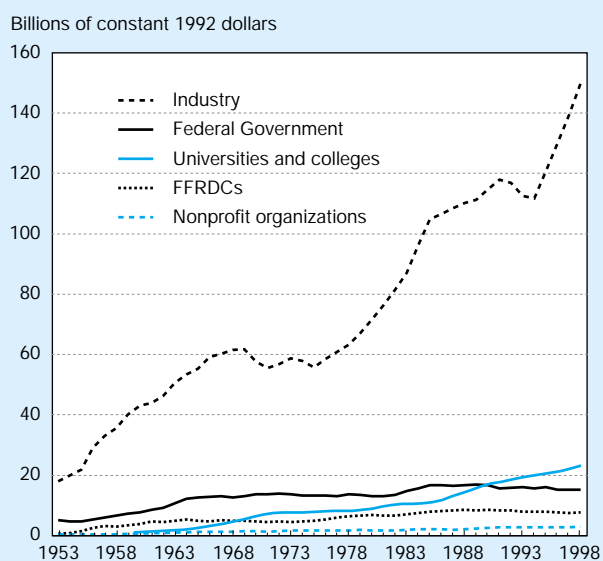
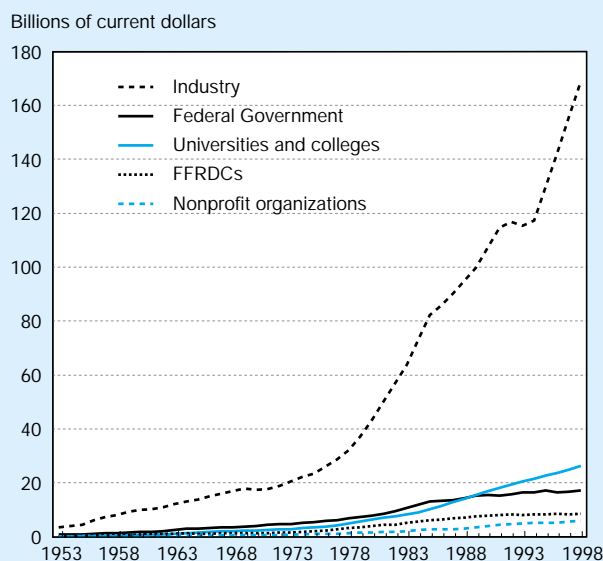
Sources of R&D Expenditures

Science—The Endless Frontier included pre-World War II data on sources of national R&D expenditures (Bush 1945a, 86), and *Science and Public Policy* included similar data for 1947 (Steelman 1947, vol. I, 12). According to the former, industry accounted for almost 68 percent of total national R&D expenditures in 1940, with the Federal Government accounting for about 19 percent, universities for 9 percent, and other sources for about 4 percent. (See text table 1-3 and figure 1-2.) During World War II, the Federal Government became the dominant supporter of R&D, a condition that continued during the early postwar years. In 1947, according to the Steelman report, the Federal Government accounted for approximately 54 percent of national R&D investments and industry for about 40 percent, with universities and other sources each contributing less than 4 percent. (See text table 1-3.)

After the end of World War II in 1945, industrial R&D investments increased, while Federal expenditures declined so that by the end of the decade industry was once again the leading supporter of R&D in the country. The Korean War, which began on June 25, 1950, a few days before the start of FY 1951, led to a rapid increase in defense R&D expenditures so that, beginning in 1951, Federal contributions exceeded those of industry. That situation continued until 1980, when industrial R&D investments equaled and then began to exceed those of the Federal Government. (See text table 1-3 and figure 1-2.) Since 1990, Federal R&D expenditures measured in constant dollars have declined, while those of industry, universities and colleges, and other sources have continued to increase. In 1998, industry accounted for 65.1 percent of

⁵⁰Because U.S. Government accounting conventions changed during the early 1950s, precise comparisons of current R&D expenditure levels with those in the 1940s and earlier are difficult to make. (See footnote 43.)

Figure 1-2.
National R&D performance, by type of performer: 1953–1998



FFRDC = Federally Funded Research and Development Centers

See appendix tables 2-3 and 2-4.

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national R&D investments, the Federal Government 30.2 percent, the academic sector 2.3 percent, and other sources 2.4 percent. (See chapter 2.)

Today, both *Science in the National Interest* and *Unlocking Our Future* emphasized that Federal Government R&D expenditures will remain constrained during the foreseeable future and that industry will continue to be the dominant funder of R&D. Both also noted the importance of the complementary support roles of government and industry in maintaining the vitality of the total national science and engineering system.

Role of Nonprofit Organizations

A unique aspect of the U.S. system is the role that nonprofit organizations play in the support and conduct of research. One of the four committee reports appended to *Science—The Endless Frontier* included pre-World War II expenditure estimates for research support by nonprofit organizations (Bush 1945a, 86). In 1940, these amounted to approximately \$4.5 million, compared with an estimated \$31.5 million expended by universities for their research. *Science and Public Policy* acknowledged that, although nonprofit organizations had played important roles in supporting basic research, their expenditures were unlikely to increase significantly (Steelman 1947, vol. I, 27). This assertion provided one basis for the argument that a stronger Federal role in basic research support was essential.

Today, nonprofit organizations accounted for an estimated \$3.4 billion in R&D expenditures in 1998, compared with the approximately \$5.0 billion expended for R&D by universities and colleges from their own sources. Research facilities operated by nonprofit organizations received an estimated \$2.9 billion in Federal support for their research during that same year. These facilities occupy a unique, important niche in the national research system. After having been eclipsed as significant sources of research support, nonprofit organizations and their strategic roles are again being recognized—particularly in technology development and health-related research. For this reason, NSF is currently conducting a substantial study that aims to determine in more detail the current roles of nonprofit organizations in the U.S. science and engineering enterprise. (See chapter 2.)

Defense R&D

The importance of scientific research and engineering development to national security has been among the most enduring science policy themes. *Science—The Endless Frontier* recommended that a Division of Defense Research should be established within the proposed National Research Foundation and allocated approximately 30 percent of its budget during the first year, decreasing in relative terms to about 16 percent by the fifth year (Bush 1945a, 40). (See text table 1-5.) This division would have been authorized to support defense-related research in civilian institutions without recourse to, or approval by, any military authority.

By contrast, *Science and Public Policy* argued that Federal R&D allocations were distorted, with defense-related expenditures too large relative to nondefense components. In 1947, the combined R&D budgets of the War and Navy departments accounted for 80 percent of all Federal R&D expenditures. (See text table 1-4.) The report recognized that the absolute level of defense R&D was probably appropriate and that there was no short-term prospect for any significant reduction (Steelman 1947, vol. I, 21–3). Therefore, it recommended that, over the long term, greater emphasis should be placed on increasing other components of the Federal R&D budget so that by 1957, defense R&D would account for 22 percent of the total.

Today, both defense and nondefense R&D expenditures have grown to levels vastly higher than envisaged 50 years

Text table 1-5.

Proposed National Research Foundation budget

In millions of U.S. dollars

Activity (by division)	First year			Fifth year		
	1945 current	1998 constant	Percent	1945 current	1998 constant	Percent
Medical research	5.0	41.3	14.9	20.0	165.4	16.3
Natural sciences	10.0	82.7	29.9	50.0	413.4	40.8
National defense	10.0	82.7	29.9	20.0	165.4	16.3
Scientific personnel and education	7.0	57.9	20.9	29.0	239.8	23.7
Publications and collaboration	0.5	4.1	1.5	1.0	8.3	0.8
Administration	1.0	8.3	3.0	2.5	20.7	2.0
Total	33.5	277.0	100.0	122.5	1,012.9	100.0

NOTE: Details may not sum to totals because of rounding.

SOURCE: Vannevar Bush, *Science—The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research* (1945a). Reprinted by NSF (Washington, DC: 1990).

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ago, each responding to changing needs and opportunities.⁵¹ During the Strategic Defense Initiative era of the 1980s, defense R&D expenditures accounted for almost 80 percent of the total Federal R&D budget. But that situation has changed. The fraction of defense R&D in the Federal R&D budget, which by 1989 had declined to approximately 61 percent of all Federal R&D expenditures, continued to decline to 48.5 percent in 1997. The Clinton Administration's budget for fiscal year 2000 proposed expending \$35.1 billion for defense R&D, or 44.5 percent of the \$78.2 billion proposed for total Federal R&D expenditures.⁵² (See chapter 2.)

Health-Related Research

Among the unique characteristics of the U.S. system is the high level of support that the Federal R&D budget allocates to health-related research. But this was not the case in the late 1940s. One of the four committee reports appended to *Science—The Endless Frontier* dealt exclusively with health research and laid particular emphasis on the need to increase support for basic research underlying medical advances (Bush 1945a, 46–69). The body of the report recommended that a Division of Medical Research should be established within its proposed National Research Foundation and allocated 15 to 16 percent of its total budget (Bush 1945a, 40). (See text table 1-5.) *Science and Public Policy* argued that Federal investments in health-related research were inadequate. It recommended that these investments should be tripled during the next 10 years so that they would then constitute 14 percent of the Federal R&D budget (Steelman 1947, vol. I, 28).

Today, health-related R&D accounts for the largest fraction of the Federal nondefense R&D budget. In FY 1999, the

R&D budget of the Department of Health and Human Services was \$15.8 billion—almost 20 percent of total Federal R&D budget, and slightly less than 38 percent of Federal non-defense R&D (NSF 1998). *Science in the National Interest* assigned a high priority to health as a core element of the national interest, emphasizing that a wide range of scientific disciplines, including the physical, social, and behavioral sciences, in addition to the biomedical sciences, make essential contributions (Clinton and Gore 1994, 3). (See chapter 2.)

Centrality of the University System

Support for University Research

Science—The Endless Frontier's recommendation that the Federal Government should assume major responsibility for supporting research in universities was, of course, its most novel feature; the proposed National Research Foundation was to be the principal means for discharging this new function. Bush proposed that the budget for the new agency should be \$33.5 million for the first year, rising to a steady state level of \$122.5 by the fifth year (Bush 1945a, 40). (See text table 1-5.) These amounts were to be allocated to research in all fields of science, including defense and medical research (but excluding the social sciences) and to a scholarship and fellowship program.

Science and Public Policy also emphasized the Federal role in supporting university research. Following Bush, it recommended the creation of a National Science Foundation, but excluded the defense research support function proposed by Bush, while explicitly including support for the social sciences.⁵³ The report recommended that the initial budget of the proposed National Science Foundation should be \$50 mil-

⁵¹Compare this with Office of Science and Technology Policy (1995). This policy document, based on a White House Forum held at NAS March 29–30, 1995, considered environmental and economic security issues as well as military security.

⁵²*Budget of the United States Government for Fiscal Year 2000*, Executive Summary, p. 107, table 7-1.

⁵³See Steelman (1947, vol. I, 31–2). Section 3(a)(2) of the National Science Foundation Act of 1950 “directed and authorized” the Foundation to support research in the “mathematical, physical, medical, biological, engineering, and other sciences.” The 1968 Daddario Amendments to the National Science Foundation Act added the social sciences to this enumeration.

lion, rising to \$250 million after 10 years when it should account for 20 percent of the total Federal R&D budget.

Today, because recommendations from these key policy documents of the early transition period were taken seriously, universities have come to occupy the vital center of the U.S. national research system, a situation which is unique to the United States. Both *Science in the National Interest* and *Unlocking Our Future* explicitly recognize their central roles, and there is a widespread consensus about the need to provide adequate support for university research. Issues now have to do with the balance of support for academic research among fields and disciplines. The significance of interdisciplinary research to address national objectives is increasingly stressed, as is the importance of research in the social and behavioral sciences.⁵⁴ (See chapter 6.)

Support for University Research Facilities

One of the four committee reports appended to *Science—The Endless Frontier* included pre-World War II data on capital expenditures for university research (Bush 1945a, 87). *Science and Public Policy* emphasized that “additional libraries, laboratory space and equipment are urgently needed, not only in terms of the [report’s] contemplated program of basic research, but to train scientists for research and development programs in the future” (Steelman 1947, vol. I, 37). It urged that provision be made for Federal aid to educational institutions for the construction of facilities and the purchase of expensive equipment.

Today, there is still concern about the adequacy of academic research facilities. As evidence of the bipartisan character of its interest, Congress requires NSF to issue a periodic report on the state of academic facilities for basic research. (See chapter 6.)

Human Resources for Science and Engineering

Supply and Demand for Scientists and Engineers

The deficit of trained scientists and engineers resulting from World War II was one of the primary concerns of both *Science—The Endless Frontier* and *Science and Public Policy*. The Bush report included a section on this problem, entitled “Renewing our Scientific Talent” (Bush 1945a, 23–7). A chapter on human resources in volume I of the Steelman report estimated that there was at that time (1947) a deficit of 90,000 scientists at the bachelor’s level and 5,000 at the doctoral level (Steelman 1947, vol. I, 15–23). It went on to estimate, on the basis of demographic data, that it would require 10 years before the numbers of scientists at these two levels would reach the numbers that might have reasonably been expected if World War II had not intervened. By the mid-1950s these deficits had largely been alleviated, thanks in part to educational support provided to returning veterans by the GI bill of rights and, beginning in the early 1950s, to Federal Govern-

ment predoctoral and postdoctoral fellowship programs.⁵⁵

Today, demand for scientists and engineers continues to be high, although there is considerable variation by field and sector. Unemployment rates for this population are consistently lower than for persons trained at similar levels in other fields, while employment in the science and engineering sector is projected to increase at more than three times the rate for all occupations. (See chapter 3.)

Research by Academic Faculty

Science and Public Policy paid particular attention to human resources in the academic sector. It emphasized the importance of the links between research and teaching responsibilities of faculty in U.S. colleges and universities that had both research and teaching responsibilities, but the conditions then prevailing in those institutions frequently did not permit faculty to exercise those responsibilities effectively (Steelman 1947, vol. I, 19–20). Teaching loads had increased significantly since the end of World War II as a result of the doubling of the number of science and engineering students—many of them returning veterans—over prewar levels. One result was a diminished capacity for research in the academic sector. The report estimated that it would take 15,000 additional qualified science and engineering instructors to restore the prewar student–teacher ratio in U.S. colleges and universities.

Today, tenure track positions in colleges and universities are highly competitive. This has led to considerable demoralization among younger scientists, owing to diminishing opportunities to obtain positions either in academia or industry where they can continue to pursue the type of basic research they performed as graduate students. The amount of research experience required to qualify for a tenure track position has continued to increase. As a result, a large percentage of recent Ph.D.s aspiring to academic careers hold postdoctoral positions, which were relatively rare in the 1940s. There is widespread concern that academia is “overproducing” Ph.D.s—particularly for academic positions. After years of relative neglect, establishing effective links between research and education has reemerged as a salient policy issue. (See chapter 3.)

Science and Engineering Education at the Undergraduate and Graduate Levels

Science and Public Policy pointed out that the above-noted shortages of qualified science and engineering instructors in U.S. colleges and universities, coupled with increasing enrollments, was also undermining the quality of undergraduate science and engineering education (Steelman 1947, vol. I, 16–20). Neither *Science—The Endless Frontier* nor *Science and Public Policy* considered details of graduate study curricula explicitly. However, the latter included a report commissioned from AAAS on “The Present Effectiveness of Our Schools in the Training of Scientists,” which discussed the

⁵⁴NSF created a Directorate for Social, Behavioral, and Economic Sciences in January 1992.

⁵⁵The first NSF fellowships, consisting of 535 predoctoral and 38 postdoctoral awards, were made in the spring of 1952 at a total cost of \$1.53 million, or approximately \$8.7 million in constant 1998 dollars (NSF 1952, 55, 75).

recruitment, retention, and support of graduate students in science and engineering (Steelman 1947, vol. IV, 131–40).

Today, after several years of rapid expansion, enrollments in higher education in the United States have leveled off. Issues associated with graduate education in science and engineering remain salient, particularly the retention, training, and support of graduate students.⁵⁶ (See chapter 4.)

Foreign Students in U.S. Universities

Science and Public Policy recommended that foreign students should be encouraged to attend U.S. colleges and universities, noting that it might be some time before most of the first-rate European institutions would recover completely from the devastation of World War II (Steelman 1947, vol. I, 39–40). It conceded that the crowded conditions then prevailing at many of these institutions might make it difficult for them to accept too many foreign students. On the other hand, it suggested such a program, which it noted might be supported through the recently established Fulbright Program for International Educational Exchange, would be an important contribution to international goodwill.⁵⁷

Today, foreign-born students are a significant presence in U.S. universities, particularly in science and engineering programs at the graduate level. Asian students predominate. There is some concern about the fact that the number of foreign students in some disciplines is larger (in some cases far larger) than the number of U.S. students. (See chapter 4.)

Elementary and Secondary Education

Both *Science—The Endless Frontier* and *Science and Public Policy* recognized the importance of elementary and secondary education. The former report emphasized that “improvement in the teaching of science is imperative, for students of latent scientific ability are particularly vulnerable to high school teaching, which fails to awaken interest or to provide adequate instruction. To enlarge the group of specially qualified men and women it is necessary to increase the number who go to college” (Bush 1945a, 26). One of its four appended committee reports included a section entitled “The Education Pyramid: Studies Concerning Able Students Lost to Higher Education” (Bush 1945a, 166–76). Although data specific to mathematics and science education were not included, the section urged that improvements in instruction in all subjects were essential if a greater proportion of qualified students were to go on to higher education.

Volume IV of *Science and Public Policy*, which was devoted entirely to human resources for science and engineering, included an extensive survey and analysis of the condition of mathematics, science, and engineering education from the primary through the undergraduate–graduate levels (Steelman 1947, vol. IV, 47–162). This analysis pointed to a number of

deficiencies in mathematics and science instruction at the elementary and secondary levels and made specific recommendations for remedial action.

Today, student achievement, curriculum and instruction, and teacher preparation have become issues of national importance. Repeated studies during the past three decades indicate that U.S. students do not perform as well in mathematics or science as do their peers in many other nations. More recent studies point to a far less challenging curriculum and less demanding instructional practices as key factors in that performance. Minority students and women tend to perform less well and to take fewer demanding mathematics and science courses. (See chapter 5.)

Significance of Industrial R&D

R&D and Economic Growth

Both *Science—The Endless Frontier* and *Science and Public Policy* emphasized the importance of R&D to economic growth. The former dealt with the theme in terms of science, technology, and job creation noting that,

one of our hopes is that after the war there will be full employment, and that the production of goods and services will serve to raise our standard of living. There must be a stream of new scientific knowledge to turn the wheels of private and public enterprise. There must be plenty of men and women trained in science and technology for upon them depend both the creation of new knowledge and its application to practical purposes (Bush 1945a, 6).

Science and Public Policy approached the economic growth theme in terms of U.S. leadership stressing that, “if we are to remain a bulwark of democracy in the world, we must continually strengthen and expand our domestic economy and our foreign trade. A principal means to this end is through the constant advancement of scientific knowledge and the consequent steady improvement of our technology” (Steelman 1947, vol. I, 3–4).

Today, the importance of science-related and high-technology industries in terms of both job creation and international standing is widely recognized. (See chapter 7.) *Science in the National Interest* emphasized prosperity as a core element of the national interest, stating that “Prosperity requires technological innovation. Basic scientific and engineering research is essential for training innovative scientists and engineers, for many technology improvements, and for achieving the revolutionary advances that create new industries” (Clinton and Gore 1994, 4).

Domestic Competition

Science and Public Policy gave several reasons for the impressive increase in industrial R&D expenditures during the two years since the end of World War II. In particular, it noted that “competition, in many instances, is forcing a rapid exploitation of scientific advances” (Steelman 1947, vol. I, 22).

Today, successful competition in the domestic market relies heavily on industrial R&D investments. *Unlocking Our Future* noted that:

⁵⁶See, for example, NSB (1997).

⁵⁷An Act To Amend the Surplus Property Act of 1944 To Designate the Department of State as the Disposal Agency for Surplus Property Outside the United States. Public Law 79-584, enacted August 1, 1946. Senator William J. Fulbright of Arkansas introduced provisions in this legislation to permit the use of U.S.-owned foreign currency for educational exchanges.

Today's technology-driven company must bridge the research gap between basic science and product development if it wants to remain on the cutting edge of the industry. This research is typically necessary to develop basic research results into an emerging technology and then into a marketable product (U.S. House of Representatives Science Committee 1998, 24).

Increasing competition has led to a fundamental structural change in the character of industrial research. Formerly, a good deal of that research, including a reasonable amount of basic research, was conducted in centralized corporate laboratories. However, most of that research has been divested to individual business units on the grounds that research results can thereby be captured more immediately and effectively for commercial developments. The decline of corporate research laboratories as performers of basic research has increased the importance of university basic research to industry, indicating the need for effective partnerships between these two sectors. (See chapter 7.)

International Competition

Science and Public Policy emphasized that the economic and technological supremacy that the United States enjoyed in 1947 was a partial result of the wartime devastation that other industrialized countries had experienced. It went on to warn that,

the future is certain to confront us with competition from other national economies of a sort we have not hitherto had to meet. Many of these will be state-directed in the interest of national policies. Many will be supported by new, highly efficient industrial plant and equipment—by the most modern technology. The destructiveness of the recent war makes it inevitable that much of Europe, in rebuilding its factories, will soon possess an industrial plant more modern than ours today (Steelman 1947, vol. I, 4).

Today, high-technology exports are a critical contributor to the U.S. balance of trade. The United States is dominant in the export of technology. However, in some vital areas of technology, the capabilities of Japan or one or more European countries are at least on a par with those of the United States, and in a few cases may actually exceed those of this country. High-technology competition from several emerging economies is also increasing. (See chapter 7.)

The Federal Role

Support for Science and Engineering Students

Both *Science—The Endless Frontier* and *Science and Public Policy* recommended that the Federal Government should establish undergraduate scholarship and graduate fellowship programs as a means to alleviate the wartime deficit of scientists and engineers (Bush 1945a, 26–7; Steelman 1947, vol. I, 7). Both emphasized that, in addition to helping relieve the deficits, an undergraduate scholarship program would make it possible for all qualified students to obtain a college education even if their families lacked the requisite financial resources. For that reason, both recommended that the scholarship program should encompass fields other than science and engi-

neering. The recommended undergraduate scholarship programs were never implemented in the form recommended by the two reports. However, Title II of the Servicemen's Readjustment Act of 1944, commonly known as the GI bill of rights, provided support for returning veterans to attend college and led to the results that both reports had hoped would occur—namely, the democratization of U.S. higher education.⁵⁸

Today, the democratization of higher education has improved, in the sense that more qualified students are able to obtain an education at the undergraduate level. Nonetheless, there are serious concerns about unevenness in demographic representation in science and engineering fields, particularly for women and for racial and ethnic minorities. (See chapter 4.) Additionally, there are continuing problems with and differences in the quality of K–12 education throughout the Nation, a factor influencing access to higher education. (See chapter 5.)

Federal Role Vis-à-Vis Industrial Research

Then as now, the appropriate role of the Federal Government *vis-à-vis* the industrial research sector was an issue of primary importance. *Science—The Endless Frontier* took the position that the Federal Government should not provide direct financial support for nondefense research in industry, nor interfere in any way with industry's prerogative to determine its own research priorities and directions. It asserted that "the simplest and most effective" way that government could assist industry would be to support basic research in universities and help ensure that there would be an adequate number of trained scientists and engineers. The report also recommended clarification of the tax code on the matter of the deductibility of R&D expenditures and a simplification of the patent system to reduce the cost of patent filing, in part because filing costs often discouraged businesses from investing in R&D (Bush 1945a, 21).

While agreeing that industry should determine its own research priorities, *Science and Public Policy* was more flexible on the matter of Federal support. In fact, it argued that Federal Government expenditures for nondefense development were too small relative to its defense expenditures. The report noted that, of the estimated \$625 million expended by the Federal Government for R&D in contracts to industrial and university laboratories in 1947, \$500 million was accounted for by the Departments of War and Navy.⁵⁹ (See text table 1-4.) In addition to increasing support for university research by a factor of four by 1957, it recommended doubling support for nondefense development so that it would constitute 44 percent of the Federal R&D budget by that same year (Steelman 1947, vol. I, 28).

Today, both *Science in the National Interest* and *Unlocking Our Future* emphasized intersectoral partnerships and alliances as key elements in a vital national research system. The importance and legitimacy of the Federal role in cata-

⁵⁸Public Law 78-346, enacted June 22, 1944.

⁵⁹The Departments of War and Navy were combined into the Department of Defense in 1947.

lyzing and facilitating partnerships and alliances is widely accepted. In addition, there are also a few relatively modest Federal programs to provide partial support for particularly risky research in industry. (See chapter 7.)

Coordination of Federal Research Policy and Programs

Volume II of *Science and Public Policy* was devoted entirely to “The Federal Research Program,” while volume III dealt with “Administration for Research.” The principal conclusions of these volumes were summarized in a chapter in the first, summary volume titled “Federal Organization for Science” (Steelman 1947, 61–7). This chapter recommended that “(1) An Interdepartmental Committee for Scientific Research should be created; (2) The Bureau of the Budget should set up a unit for reviewing Federal scientific research and development programs; and (3) The President should designate a member of the White House staff for scientific liaison.”

Today, all of these recommendations have been implemented. The functions of the Interdepartmental Committee for Scientific Research and Development, which was created in December 1947 and became the Federal Coordinating Committee for Science and Technology in November 1957, were later expanded and subsumed by the FCCSET, which was established in 1976 by the same Act of Congress that created the OSTP.⁶⁰ In 1993, FCCSET was subsumed in turn into the NSTC, which is chaired by the President and includes the heads of all Federal agencies and bureaus with significant science and technology responsibilities, as well as other Federal Government officials—most prominently the President’s Assistant for Science and Technology (commonly known as the President’s Science Advisor) and the director of the Office of Management and Budget. These two officials have been working together closely for several years to develop a coherent Federal R&D budget aimed at addressing administration science and technology priorities. At the beginning of each annual budget cycle, they co-sign a letter to the heads of all relevant agencies that contains instructions relevant to the preparation of budget proposals in specific categories related to the priorities and strategic goals of the Administration. The Congress also remains concerned with the problem of ensuring that the Federal Government’s science and technology programs effectively address significant national issues, as evidenced most recently in *Unlocking Our Future* (U.S. House of Representatives Science Committee 1998).

International Considerations

International Aspects of U.S. Science Policy

Science and Public Policy recommended that, as part of the Marshall Plan proposed by Secretary of State George C. Marshall at the June 5, 1947, Harvard University commencement, “every effort [should] be made to assist in the reconstruction of European laboratories” (Steelman 1947, vol. I, 7). It also recommended that scientific missions should be

established in U.S. embassies in scientifically important countries and that foreign students should be encouraged to study in U.S. universities (Steelman 1947, vol. I, 38–40). *Science—The Endless Frontier* emphasized the importance of international exchange of scientific information to the U.S. research enterprise (Bush 1945a, 22). It recommended Federal Government support for (1) American scientists to attend international scientific meetings abroad, (2) visits to the United States by prominent foreign scientists, (3) international fellowships for U.S. scientists, and (4) translation services.

Today, the global character of science and technology is evident from R&D investments in other countries which, particularly among a majority of the G-7 countries (Canada, France, Germany, Italy, Japan, and the United Kingdom, in addition to the United States), include substantial industrial as well as government components. (See chapter 2.) The substantial research and educational resources and science and engineering talent existing in countries throughout the world has enhanced opportunities for mutually beneficial international cooperation involving university and industry researchers, including research experience for graduate students and postdoctoral researchers.⁶¹

Beginning in the early 1950s, *Science and Public Policy*’s recommendation that scientific missions should be established in important U.S. embassies abroad began to be implemented with the appointment of Science and Technology Counselors in many of these missions. However, the number of these positions has declined considerably during the 1990s, as has the importance accorded science and technology as elements of U.S. foreign policy.⁶²

Research in the Soviet Union/Russia

Science and Public Policy pointed to the Soviet Union as the principal scientific competitor of the United States, noting that its 1947 R&D budget reportedly had increased to \$1.2 billion as compared with outlays of \$900 million in 1946 (Bush 1945a, 5–6). It also remarked that the country had embarked upon a five-year program of stepped-up training for scientists and engineers.

Today, the Soviet Union no longer exists as a political entity. R&D expenditures in Russia (which contained the major concentration of the Soviet Union’s scientific resources) have declined sharply from an estimated 2.03 percent of GDP in 1989 to about 0.73 percent in 1995. Knowledgeable U.S. observers continue to regard Russia as a scientifically and technologically significant country, noting its substantial and important past contributions to research in many disciplines. Yet they also emphasize that the country must resolve formidable economic problems before it can once again make sub-

⁶⁰Public Law 94-282.

⁶¹Several NSF programs facilitate research experiences abroad at the graduate and postdoctoral and, to some extent, the undergraduate level as well. NSF’s overseas offices in Tokyo and Paris issue frequent reports on research opportunities in Japan and Europe.

⁶²Compare this with the Carnegie Commission on Science, Technology, and Government (1992); Watkins (1997, 650–1); U.S. House of Representatives Science Committee (1998, 22–4).

stantial contributions to the global science and technology enterprise. (See chapter 2.)

Significance of Developing Countries

The Steelman report pointed to India as a country where progress was being made in the construction of new scientific research laboratories and in the training of first-rate researchers (Steelman 1947, vol. I, 41). It predicted that similar developments could be anticipated in China and in Latin America.

Today, the developed countries (primarily the United States and Canada, Western Europe, and Japan) still account for by far the largest fraction of the world's R&D expenditures, with the United States, Japan, Germany, France, and the United Kingdom expending more than 2 percent of GDP for these purposes. By contrast, the R&D expenditures of China, India, and Brazil, for example, are estimated to be somewhat less than 1 percent of their GDPs. Despite their relatively modest R&D investments, all three countries have produced world-class scientists and engineers and have developed impressive, competitive capabilities in several important areas. Many scientists and engineers from the United States and other developed countries have enjoyed cooperative working relations with colleagues from these and other developing countries for several years. (See chapters 2, 4, 6, and 7.)

Public Attitudes and Understanding of Science and Technology

Although the analysis of mathematics and science education by AAAS included in *Science and Public Policy* dealt primarily with the production of professional scientists and engineers, a section entitled “Science and General Culture” also emphasized the importance of science education for non-specialists. It suggested that “maintenance of the crucially necessary supply of research talent, and integration of the sciences into a sound ethical structure of society without which civilization cannot survive, are both dependent upon adequate representation of science in our educational system” (Steelman 1947, vol. IV, 113).

Today, both *Science in the National Interest* and *Unlocking Our Future* emphasized the importance of public attitudes and understanding both to the vitality of the science and engineering enterprise and to the Nation, particularly since understanding many significant national issues requires some familiarity with science and technology. It has also been recognized that the level of public understanding of adults is strongly correlated with the adequacy of the science and mathematics education they receive at the primary and secondary school levels.⁶³ Bipartisan support is evidenced by the consistently high level of NSF's annual education and human resources appropriations, \$689 million in FY 1999. (See chapter 8.)

⁶³The widespread consensus about the importance of science and mathematics education at the primary, secondary, and undergraduate levels is suggested by the fact that NSF's annual budget for education and human resource development currently exceeds \$600 million.

Impacts of Information Technology

Had the term “information technology” been in use in the 1940s, it might well have referred to developments in communications technology—namely, radio and perhaps even television—that had been successfully demonstrated immediately before the outbreak of World War II but were not commercialized until a few years later. *Science—The Endless Frontier* did cite radio as one of several technologies whose widespread commercialization occurred after the end of World War I. It did so to suggest, by inference, that new and at that time (1945) unimagined technologies would almost certainly result from the applications of post-World War II research. However, neither the Bush nor the Steelman reports speculated about what those future technologies might be.

But on a personal level, Vannevar Bush foresaw the development of what is now called the digital library. In an article published in the *Atlantic Monthly* in July 1945 (the same month that *Science—The Endless Frontier* was delivered to President Truman), Bush invited his readers to ...

Consider a future device for individual use, which is a sort of mechanized private file and library. It needs a name, and to coin one at random, “memex” will do. A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory (Bush 1945b).

Today, information technology, based on a merging of computer and communications technologies, has become ubiquitous. Information technology has had an impact on virtually all sectors of our economy and society, including the conduct of research, as well as on our daily lives. The digital libraries that Bush foresaw more than a half-century ago are becoming a reality, even though based on very different technologies than he envisioned. Nor did he foresee the possibilities that digital libraries separated by great spatial distances could be linked electronically and accessed from other distant locations. (See chapter 9.)

Current Emerging Themes

As discussed in “A Program for the National Science Foundation,” the NSB determined during its first year that one of its major responsibilities would be to ensure that the condition of the U.S. (and global) science and technology enterprise would be monitored. Since 1972, its *Indicators* reports have been the most visible manifestation of that determination. The NSB published a strategic plan in November 1998 that emphasized its commitment to *Science and Engineering Indicators* as an instrument for assessing the overall health of the enterprise and for providing a robust basis for decisionmaking in national science and engineering policy, as well as its determination to continually improve this instrument to serve these objectives (NSB 1998c). These reports have also provided the Board with opportunities to point to both emerging themes and to emphasize transmutations in the more traditional themes that began to be evident 50 years ago.

Among the emerging themes that the Board has identified (NSB 1998c) as important in the first decade of the 21st century are:

- ◆ globalization of research and education,
- ◆ access to and impacts of information technologies,
- ◆ environmental research and education,
- ◆ knowledge-based economy,
- ◆ partnerships and linkages,
- ◆ adequacy of the supply of well-trained scientists, engineers, and science teachers,
- ◆ education as a key determinant of social and economic progress,
- ◆ special significance of K through 12 education,
- ◆ public understanding of science and technology, and
- ◆ accountability.

Plans to address these themes are laid out in the NSB Strategic Plan (NSB 1998c). Additionally, several of these themes have been addressed by previous NSB Statements and Occasional Papers; for example:

- ◆ “Science in the International Setting” (NSB 1982),
- ◆ “In Support of Basic Research” (NSB 1993a),
- ◆ “Federal Investments in Science and Engineering” (NSB 1995),
- ◆ U.S. Science and Engineering in a Changing World (NSB 1996b),
- ◆ The Federal Role in Science and Engineering Graduate and Postdoctoral Education (NSB 1997),
- ◆ “Failing Our Children: Implications of the Third International Mathematics and Science Study” (NSB 1998a),
- ◆ “Industry Trends in Research Support and Links to Public Research” (NSB 1998b), and
- ◆ “Revised Interim Report: NSB Environmental Science and Engineering for the 21st Century” (NSB 1999a).

The Board plans to issue additional occasional papers on several of these issues during the next few years.

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